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HOUSEHOLD ENERGY



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HOUSEHOLD ENERGY

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FOREWORD

Evidence has been mounting that something is missing from secondary science teaching. More and more, students are rejecting science courses and turning to subjects that they consider to be more practical or significant. Numerous high school science teachers have concluded that what they are now teaching is appropriate for only a limited number of their students.

As their concern has mounted, many science teachers have tried to find instructional materials that encompass more appropriate content and that allow them to work individually with students who have different needs and talents. For the most part, this search has been frustrating because presently such materials are difficult, if not impossible, to find.

The Individualized Science Instructional System (ISIS) project was organized to produce an alternative for those teachers who are dissatisfied with current secondary science textbooks. Consequently, the content of the ISIS materials is unconventional as is the individualized teaching method that is built into them. In contrast with many current science texts which aim to "cover science," ISIS has tried to be selective and to limit our coverage to the topics that we judge will be most useful to today's students.

Obviously the needs and problems of individual schools and students vary widely. To accommodate the differences, ISIS decided against producing tightly structured, pre-sequenced textbooks. Instead, we are generating short, self-contained modules that cover a wide range of topics. The modules can be clustered into many types of courses, and we hope that teachers and administrators will utilize this flexibility to tailor-make curricula that are responsive to local needs and conditions.

ISIS is a cooperative effort involving many individuals and agencies. More than 75 scientists and educators have helped to generate the materials, and hundreds of teachers and thousands of students have been involved in the project's nationwide testing program. All of the ISIS endeavors have been supported by generous grants from the National Science Foundation. We hope that ISIS users will conclude that these large investments of time, money, and effort have been worthwhile.

Ernest Burkman
ISIS Project
Tallahassee, Florida

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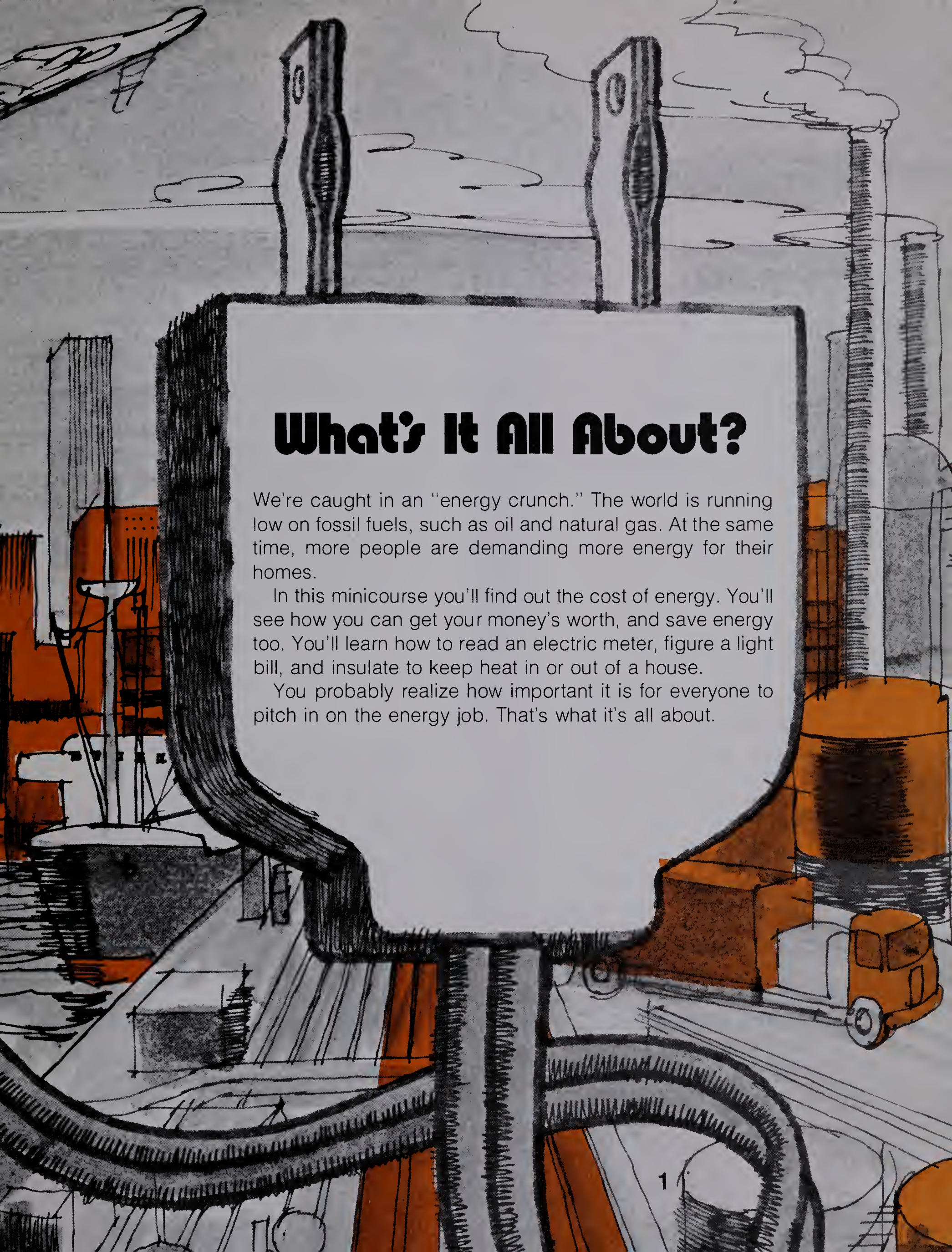
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What's It All About?

We're caught in an "energy crunch." The world is running low on fossil fuels, such as oil and natural gas. At the same time, more people are demanding more energy for their homes.

In this minicourse you'll find out the cost of energy. You'll see how you can get your money's worth, and save energy too. You'll learn how to read an electric meter, figure a light bill, and insulate to keep heat in or out of a house.

You probably realize how important it is for everyone to pitch in on the energy job. That's what it's all about.

core

Activity 1 Planning

Activity 2 Page 5

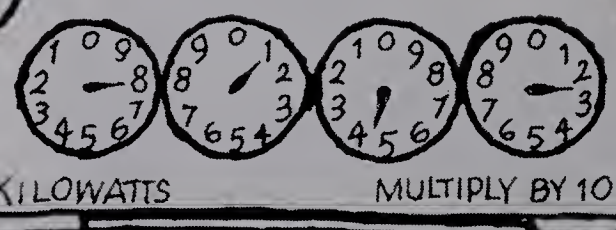
Objective 1: Define kilowatt hour and British thermal unit in terms of doing household tasks.
Sample Question: How much energy does a 500-watt washing machine use in 2 hours?

Objective 2: Define watt in terms of how fast energy is used by household electrical appliances.
Sample Question: The number of watts printed on an appliance means
a. the rate at which the appliance uses energy.
b. the voltage that must be supplied to the appliance.
c. the heat the appliance gives off.

Activity 3 Page 10

Objective 3: Compare the power used by different household devices.
Sample Question: When you are doing the washing, which uses energy faster, the electric washing machine or the electric hot-water heater that heats water for the washing?

Objective 4: Describe methods for conserving energy by decreasing the use of household devices.
Sample Question: Which would not conserve energy?
a. taking cooler showers or baths
b. skipping the drying cycle on the dishwasher
c. using the electric clothes dryer on pleasant days



Activity 4 Page 18

Objective 5: Describe how to read a meter that measures electric energy consumption.
Sample Question: What is the meter reading in kilowatt hours as indicated by the dials?

Activity 5 Page 23

Objective 6: Describe how electrical energy for the home is measured and priced.

Sample Question: The "sliding rate" electric companies use means that

a. all kilowatt hours cost the same.

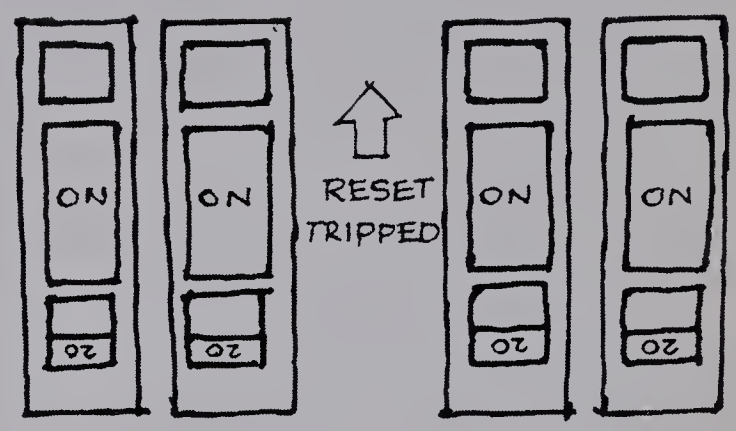
b. you pay less per kilowatt hour as amount used goes up.

c. the rate "slides" in amount from month to month.

Objective 7: Read a meter and calculate the electrical energy used and its cost.

Sample Question: Suppose a household used 864 kW h of electricity in a month. Using the rates given below, what would be the monthly bill?

First 30 kW h per month—
6.0¢ per kilowatt hour
Next 70 kW h per month—
5.3¢ per kilowatt hour
Next 200 kW h per month—
3.0¢ per kilowatt hour
Over 300 kW h per month—
2.5¢ per kilowatt hour



Activity 6 Page 27

Objective 8: Name the principal home heating methods and compare their efficiency and cost.

Sample Question: What are four common sources of energy for home heating?

Answers

1. 1 kW h 2. a 3. hot-water heater 4. c 5. 8142 kW h 6. b 7. $25.61 8. fuel oil, natural gas, electricity, and coal

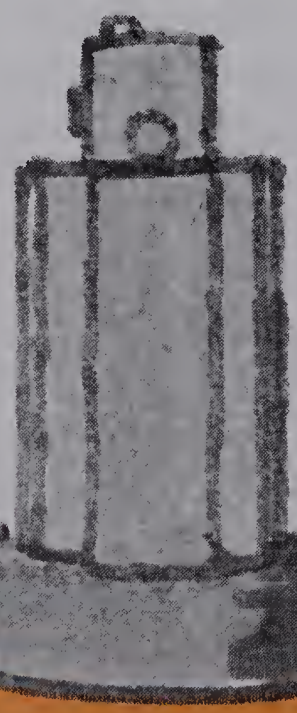
Activity 7 Page 32

Objective 9: Explain how feedback control is used by a thermostat to maintain an even home temperature.
Sample Question: In a home heating system, what happens when the thermostat senses too high a temperature?

a. The switch closes, turning on the furnace.
b. The switch opens, turning off the furnace.
c. The switch opens, turning on the furnace.

Objective 10: Describe how human comfort and energy consumption are related.
Sample Question: How is human comfort usually related to energy consumption?

a. More comfort requires more energy consumption.
b. Less comfort requires more energy consumption.
c. There is no relation.



Activity 8 Page 36

Objective 11: Describe how air conditioners and refrigerators work.
Sample Question: In what condition is a refrigerant when it leaves the compressor in an air conditioner?

a. cold
b. solid
c. hot

Activity 9 Page 39

Objective 12: Describe the benefits of insulating a house and the materials that make good insulators.
Sample Question: Which of the following could result from insulating your home?

a. lower fuel bills
b. added comfort
c. higher energy consumption

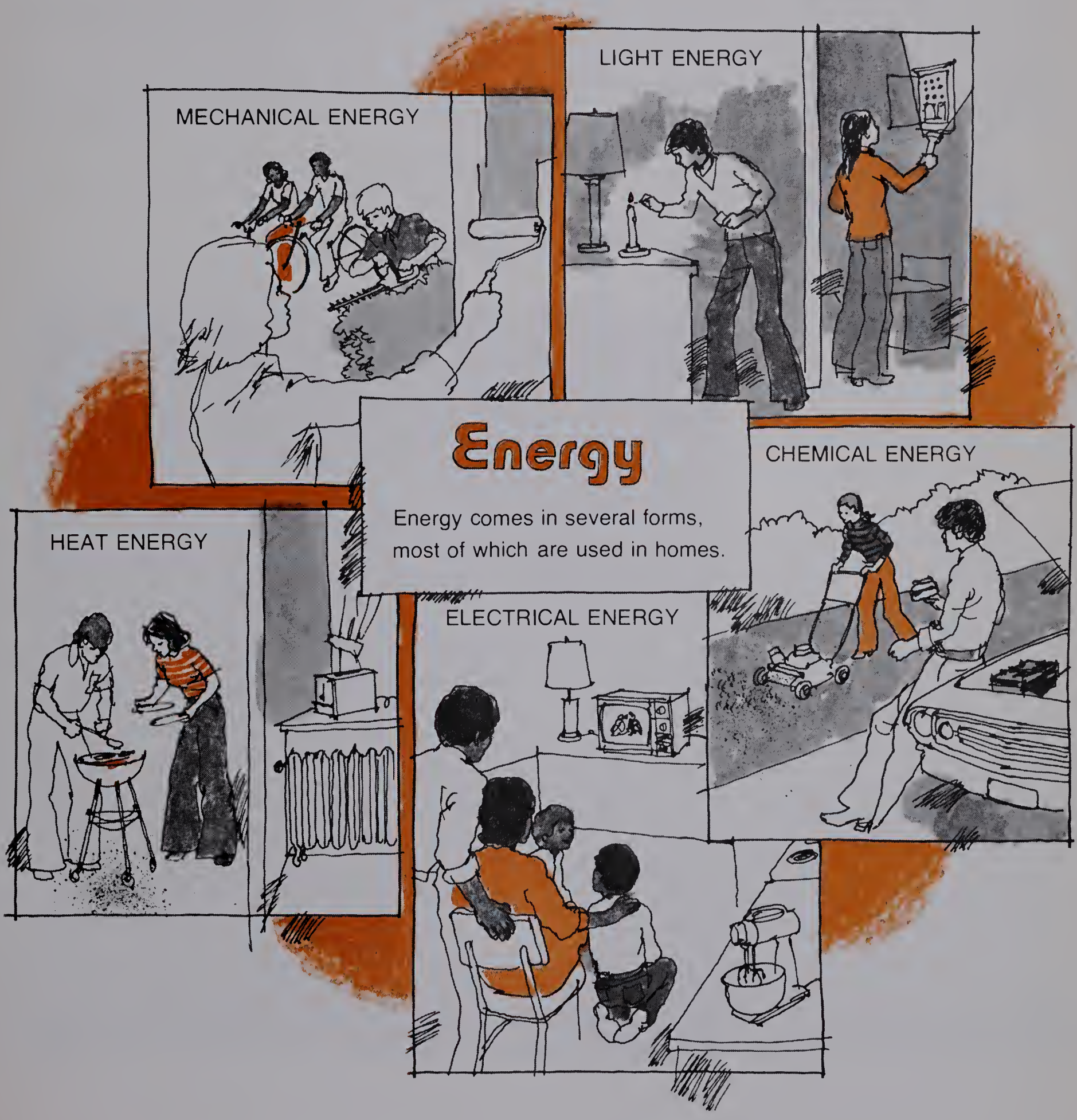
Answers
9. b 10. a 11. c 12. a and b

Using Energy



The day is gone when you could only talk about energy. Now's the time to learn what energy is and about how it's used, measured, and priced.

Energy comes in several forms, most of which are used in homes.



✔ 2–1. On page 5, why is there a lamp shown with both light energy and electrical energy?

✔ 2–2. On page 5, a lamp could be shown with what other form of energy?

✔ 2–3. What other forms of energy besides heat are involved in burning charcoal in a grill?

When the electric, fuel oil, and natural gas companies send out their bills, they're charging for energy. You pay for energy when you fill the tank at a gasoline station or buy groceries.

How do food stores and electric, fuel oil, and natural gas companies measure the energy you buy? It turns out that each measures energy differently.

Electrical Energy



Huge amounts of electrical energy are used in every community.

A meter in your home tells you how many *kilowatt hours* (kW h) of electrical energy your family uses. The watt is a unit that tells *how fast* electrical energy is used. *Kilo* means 1000, so a kilowatt hour is 1000 watts used for one hour, or

$$\text{kW h} = \frac{\text{watts} \times \text{hours}}{1000}$$

✔ 2–4. How many kilowatt hours are used by a 1000-watt electric heater in one hour?

✔ 2–5. If a 100-watt light bulb burns for 10 hours, how many kilowatt hours are used?

✔ 2–6. In 2½ hours how many kilowatt hours are used by a 400-watt electric iron?

★ **2–7. According to the labels in Figure 2–1, which appliance uses energy faster?**



Figure 2–1

Energy from Fuel Oil and Natural Gas

The energy in natural gas and fuel oil is measured in British thermal units (Btu). A Btu is a unit for measuring heat energy.



Fuel oil is measured by the gallon.



Natural gas is measured by the cubic foot.

A gallon of fuel oil releases about 137,000 Btu of heat energy when it burns. About 950 Btu of heat energy can be gotten from a cubic foot of natural gas in some localities.

★ **2–8. What kind of energy is commonly measured in British thermal units?**

Food Energy



A *calorie* is another unit for measuring heat energy. Food energy is usually measured in *kilocalories*, or *Calories* (with a capital C). A Calorie is 1000 regular calories. Sometimes Calories are called *diet calories*.

Kilowatt hours are pretty big chunks of energy. And the energy in a gallon of fuel oil or a cubic foot of natural gas is a big number of British thermal units. So that you can compare different kinds of energy, here are some small amounts that are all the same.

MECHANICAL ENERGY

The amount of energy used to lift a thick textbook one metre



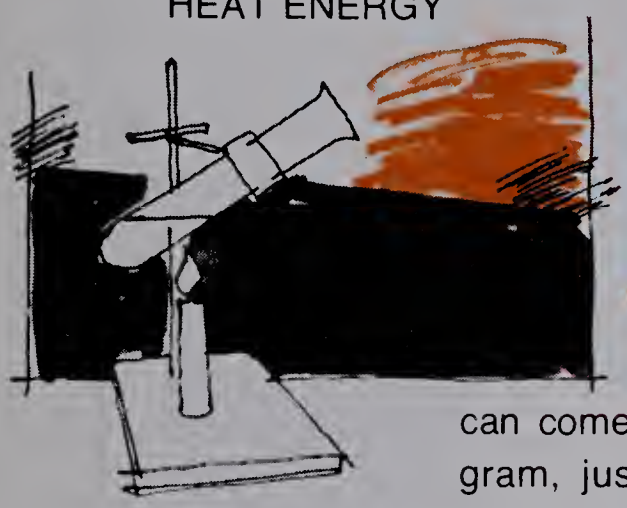
can also light the bulb of a two-cell flashlight for 10 seconds. A 100-watt bulb uses energy about 100 times as fast.

LIGHT ENERGY



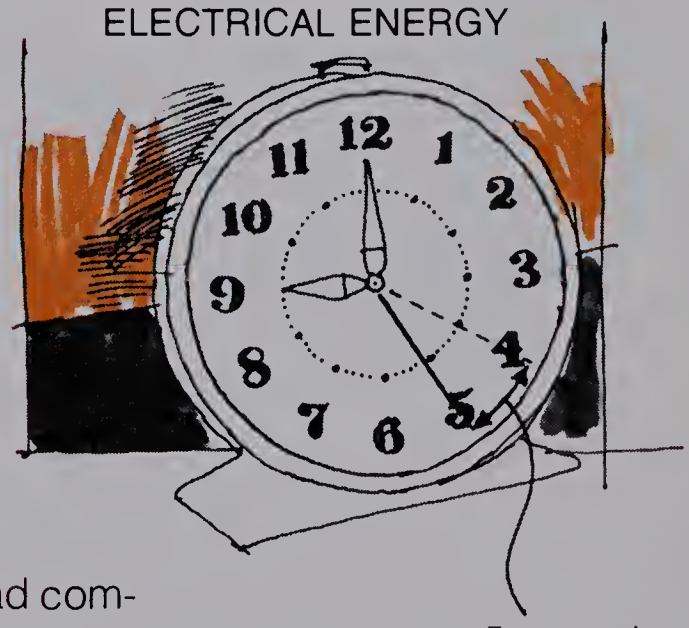
can also raise the temperature of one millilitre of water 2½°C.

HEAT ENERGY



can run the average electric clock for five seconds. In an hour the clock would use over 700 times as much energy.

ELECTRICAL ENERGY

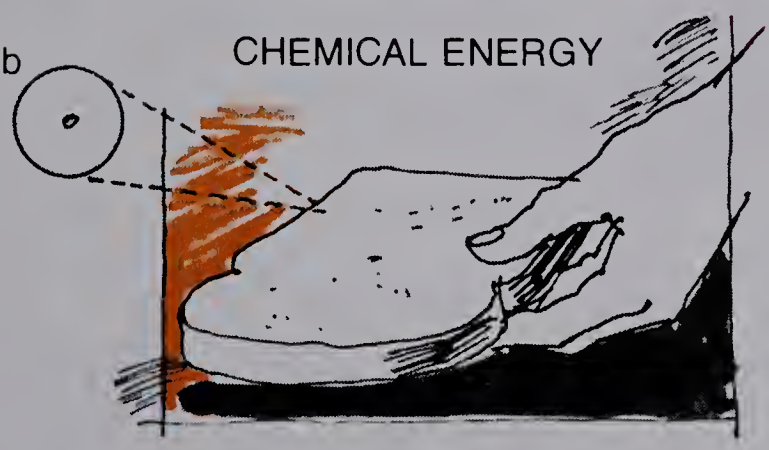


5 seconds

can come from eating one milligram, just one little crumb, of bread. The whole slice contains 25,000 times as much energy.

1 crumb

CHEMICAL ENERGY



✔ 2–9. How does the amount of energy in a slice of bread compare with that used by an electric clock in a day?

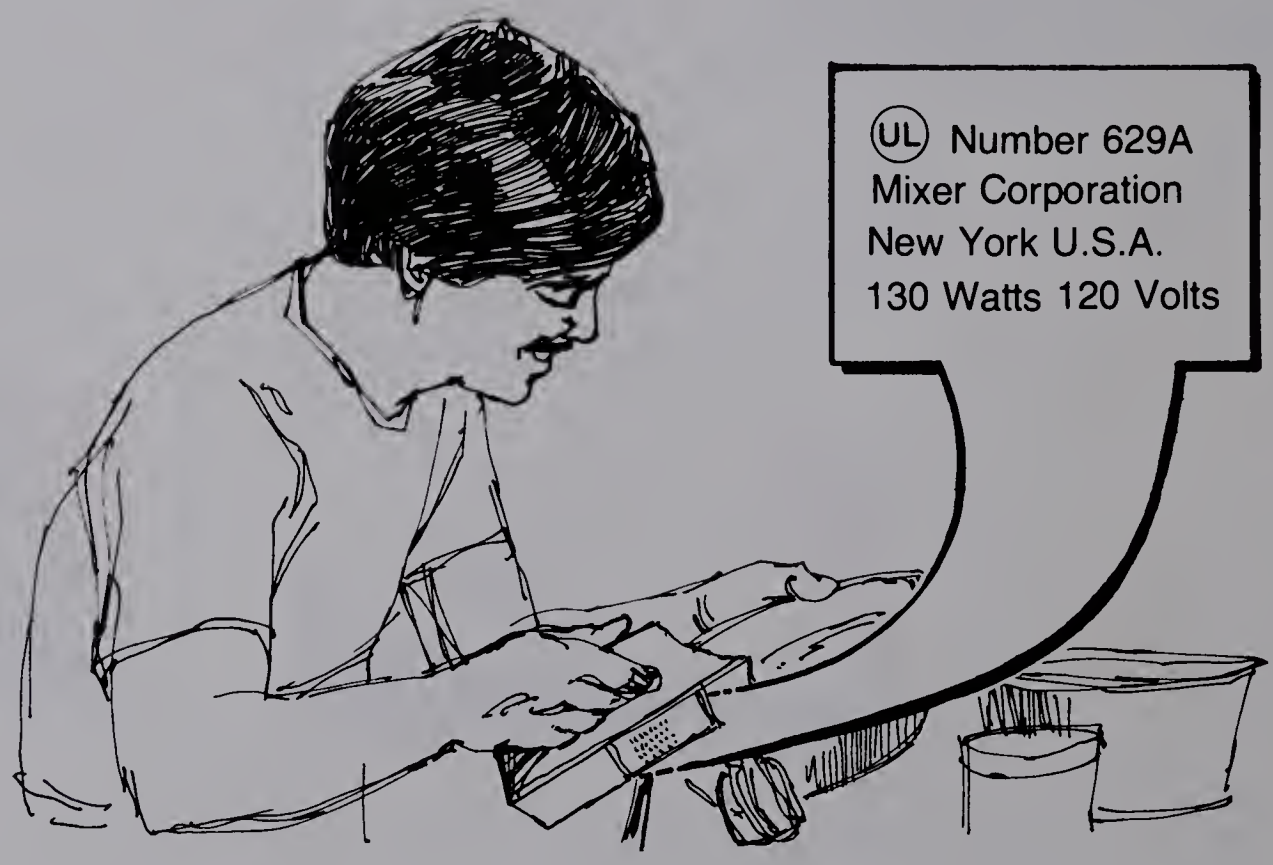
✔ 2–10. Would the amount of energy used by a 100-watt light bulb in 10 seconds be enough to raise the temperature of one millilitre of water from 0°C to 100°C?

Activity 3

Gadgets that Work for You



Energy is the capacity for doing work. Household gadgets that use energy can do work for you. Knowing how much energy an appliance uses can help you conserve energy. This may also mean you save money.



The "130 Watts, 120 Volts" on the label tells you how fast the appliance uses energy from a 120-volt outlet. Roberto uses the mixer for 10 seconds to beat eggs.

3–1. What is the wattage rating for Roberto's mixer?

You can find out how much energy the mixer used to beat the eggs by multiplying the wattage rating by the length of time it is used.

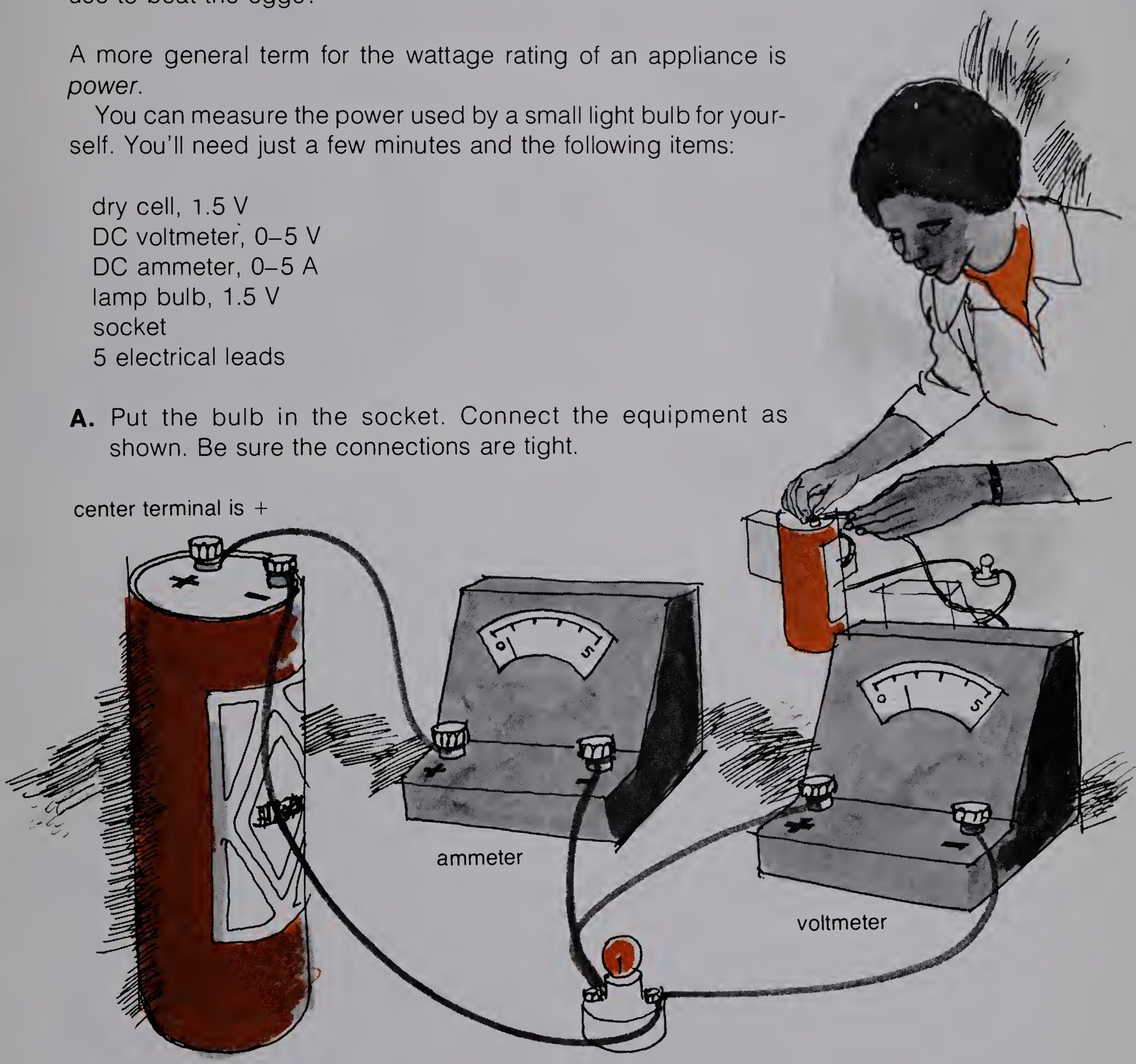
✔ 3–2. How much energy in watt seconds did Roberto's mixer use to beat the eggs?

A more general term for the wattage rating of an appliance is *power*.

You can measure the power used by a small light bulb for yourself. You'll need just a few minutes and the following items:

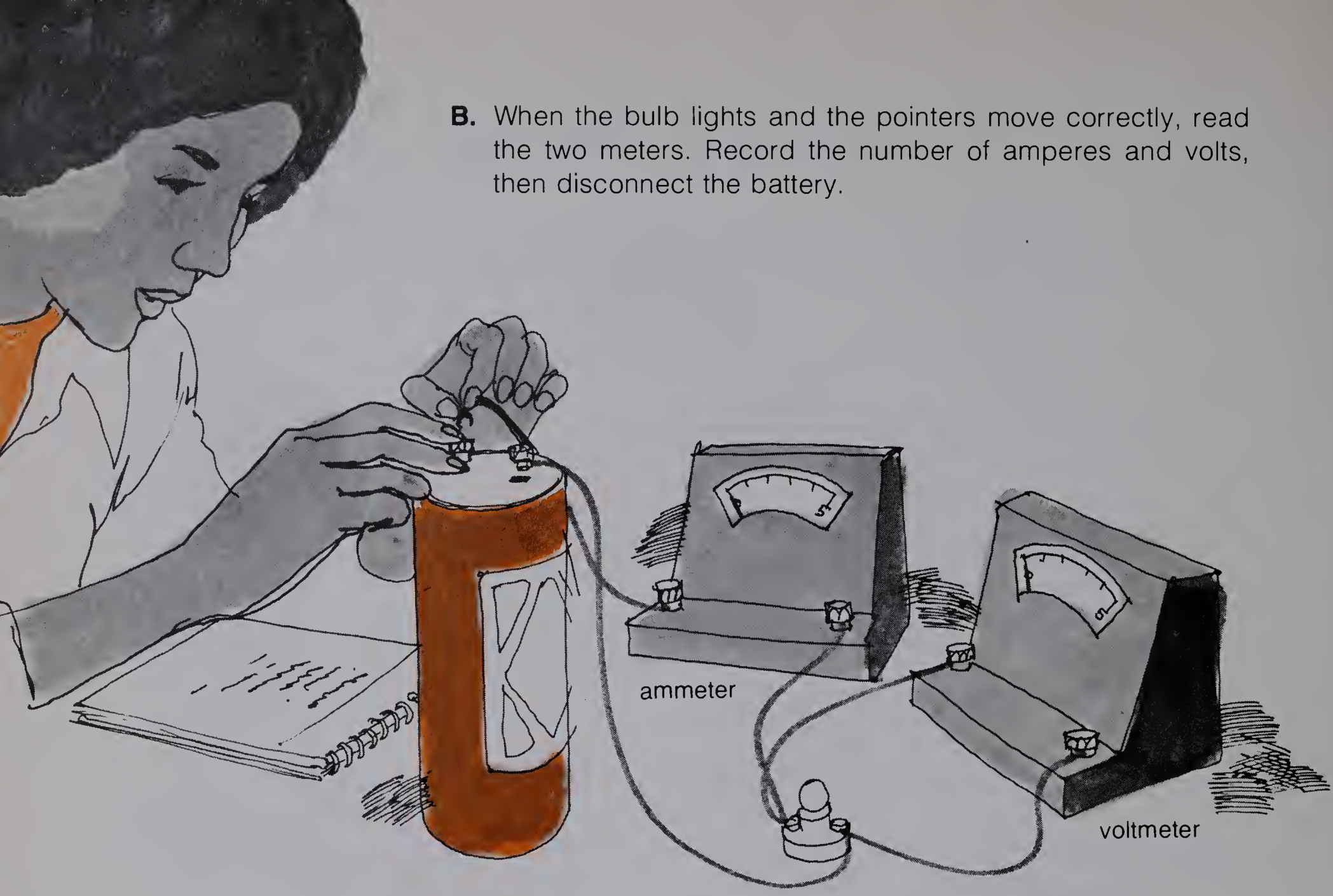
dry cell, 1.5 V
DC voltmeter, 0–5 V
DC ammeter, 0–5 A
lamp bulb, 1.5 V
socket
5 electrical leads

A. Put the bulb in the socket. Connect the equipment as shown. Be sure the connections are tight.



✔ 3–3. Does the lamp light and do the pointers on the meters move in the correct direction? If not, check your circuit again.

B. When the bulb lights and the pointers move correctly, read the two meters. Record the number of amperes and volts, then disconnect the battery.



Now you can find out how much power the light bulb uses. To do this, you multiply the number of volts by the number of amperes.

$$\text{watts} = \text{volts} \times \text{amperes}$$

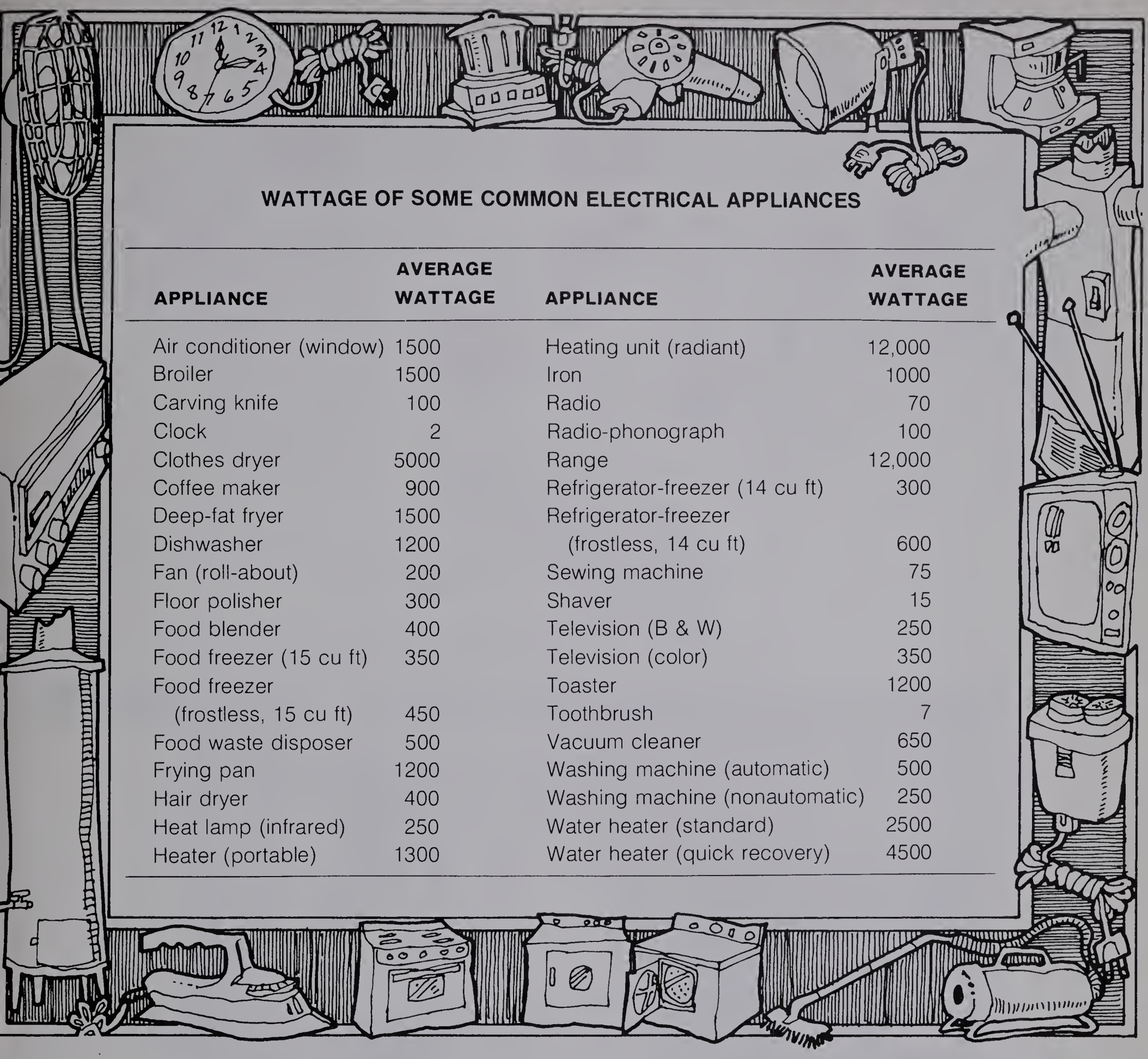
3–4. What is the voltmeter reading in volts?

3–5. What is the ammeter reading in amperes?

3–6. What amount of power in watts is the bulb using?

Your answer to Question 3–6 depends on the size of bulb you used. But the power is probably less than one watt. The little bulb doesn't use energy very rapidly. The electrical appliances in your home use energy a lot faster. For instance, the wattage rating for an electric clock is about 2, for a radio about 70, for a toaster about 1200, and for an electric stove about 12,000.

3–7. How much power does a 110-volt toaster use if it needs 11 amperes of current?



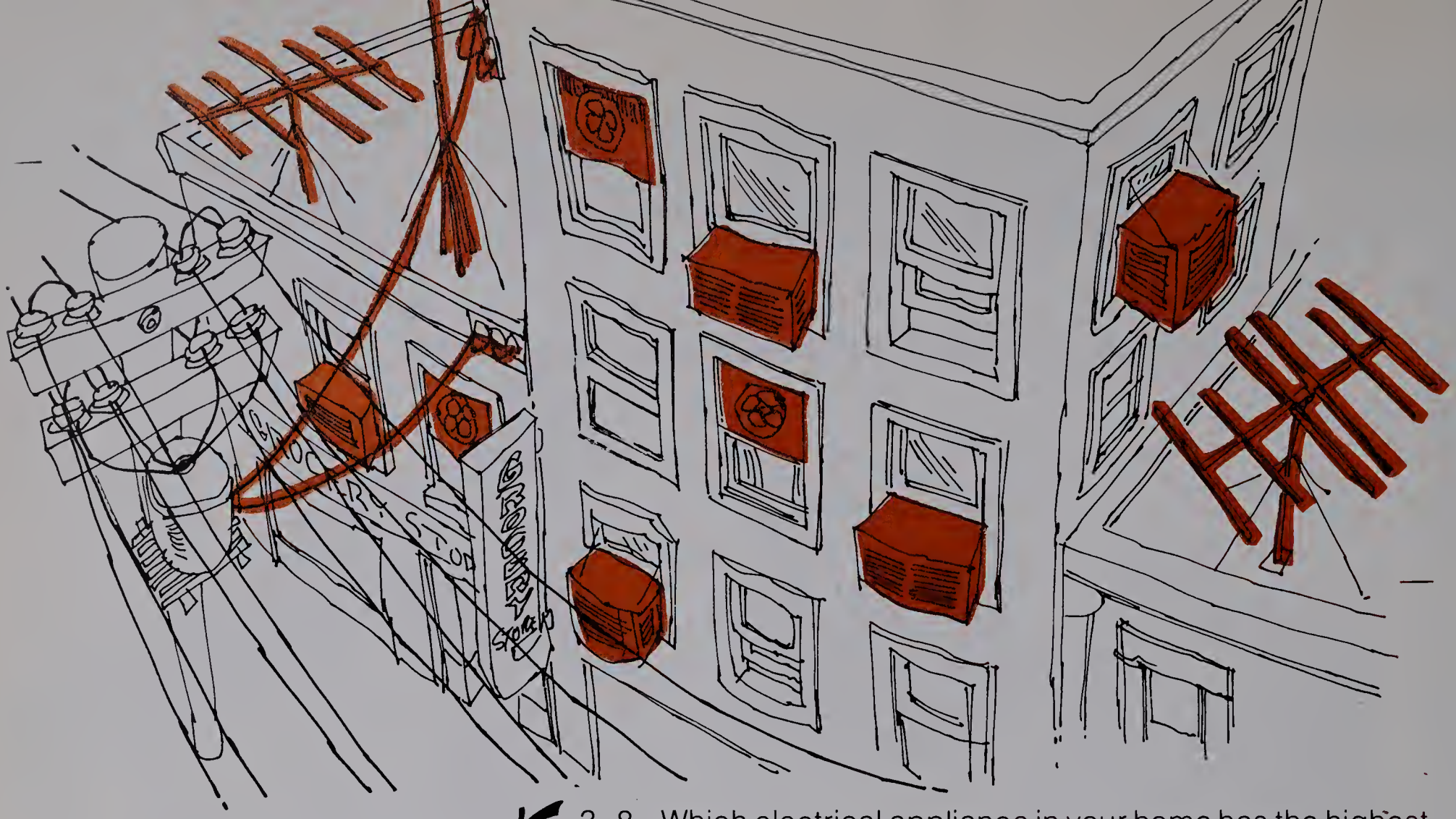
WATTAGE OF SOME COMMON ELECTRICAL APPLIANCES

APPLIANCE	AVERAGE WATTAGE	APPLIANCE	AVERAGE WATTAGE
Air conditioner (window)	1500	Heating unit (radiant)	12,000
Broiler	1500	Iron	1000
Carving knife	100	Radio	70
Clock	2	Radio-phonograph	100
Clothes dryer	5000	Range	12,000
Coffee maker	900	Refrigerator-freezer (14 cu ft)	300
Deep-fat fryer	1500	Refrigerator-freezer (frostless, 14 cu ft)	600
Dishwasher	1200	Sewing machine	75
Fan (roll-about)	200	Shaver	15
Floor polisher	300	Television (B & W)	250
Food blender	400	Television (color)	350
Food freezer (15 cu ft)	350	Toaster	1200
Food freezer (frostless, 15 cu ft)	450	Toothbrush	7
Food waste disposer	500	Vacuum cleaner	650
Frying pan	1200	Washing machine (automatic)	500
Hair dryer	400	Washing machine (nonautomatic)	250
Heat lamp (infrared)	250	Water heater (standard)	2500
Heater (portable)	1300	Water heater (quick recovery)	4500

Figure 3–1

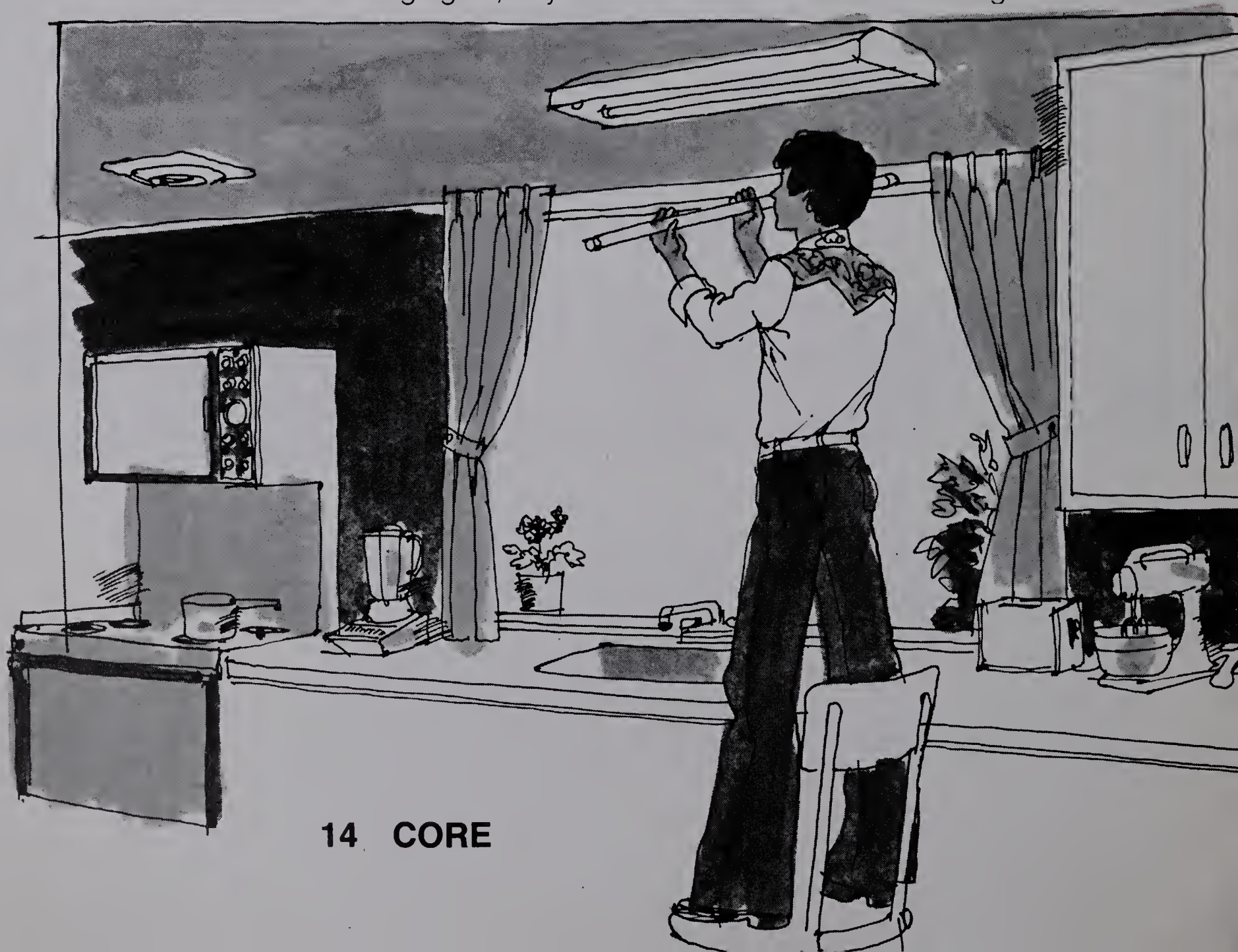
The table in Figure 3–1 shows the average wattage ratings for some common appliances. Different brands and models vary from the figures shown in the table.

Not every home will have all the appliances listed in Figure 3–1. For instance, some homes don't have window air conditioners or a food waste disposer. Electricity is not used for heating and cooking in all homes.



✔ 3–8. Which electrical appliance in your home has the highest wattage rating? The lowest wattage rating?

✔ 3–9. Estimate the wattage of all electrical appliances, including lights, in your home What is the total wattage?



What can be done to save energy? Plenty, if you know how to go about it. Using the data from Figure 3–1, let's look at some examples.

✔ 3–10. Rearrange the following appliances into two seven-item lists in your notebook. Head one list "With Heating Element" and the other "Without Heating Element." Place the wattage of each appliance beside its name.

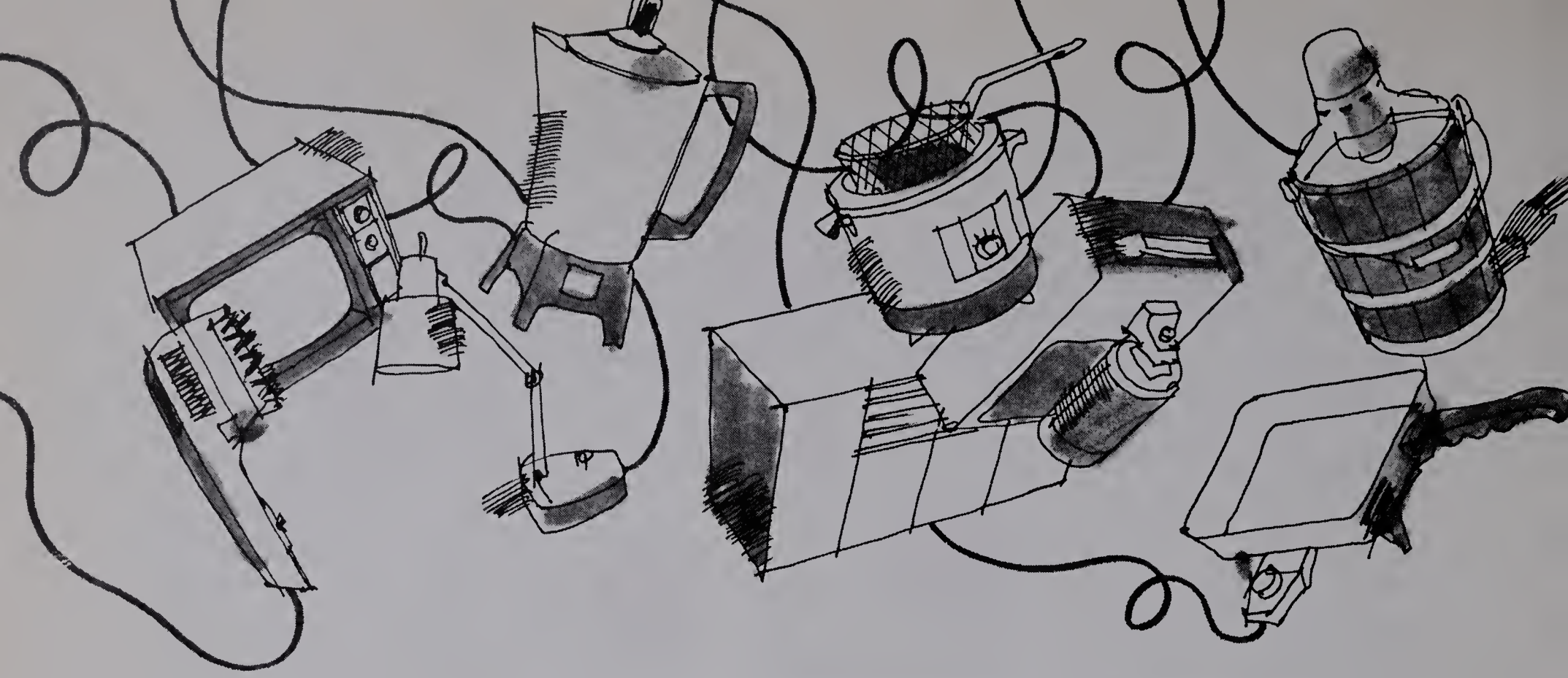
Broiler
Central heating unit
Clock
Clothes dryer
Deep-fat fryer
Dishwasher
Fan
Floor polisher
Food blender
Frying pan
Iron
Sewing machine
Shaver
Vacuum cleaner



★ **3–11. On the basis of your lists, which costs more to run, appliances with heating elements or with motors only?**

When electrical energy is changed to heat, it is used at a greater rate. It isn't going to save much energy to turn off the electric clock (and it may make you late). But cutting down on things that have heating elements will really help.

Of course, you don't turn on all the appliances at once. But the answer to Question 3–9 probably surprised you. All together, appliances represent a high rate of using energy—a large amount of power.



More and bigger gadgets are gobbling up larger amounts of power all the time. And where there are fuel shortages, energy is costing more. Anything you do to reduce power consumption will help.



✔ 3–12. What would reducing by one-third the time a hot-water heater operates do to the amount of energy used?

✔ 3–13. The drying cycle in a dishwasher accounts for half the total energy. If one load requires 1200 watt hours of energy, about how many watt hours is used in drying?

✔ 3–14. A solid state color TV uses 20 percent less energy than a regular color TV. By how much would this change the wattage for a color TV in Figure 3–1?

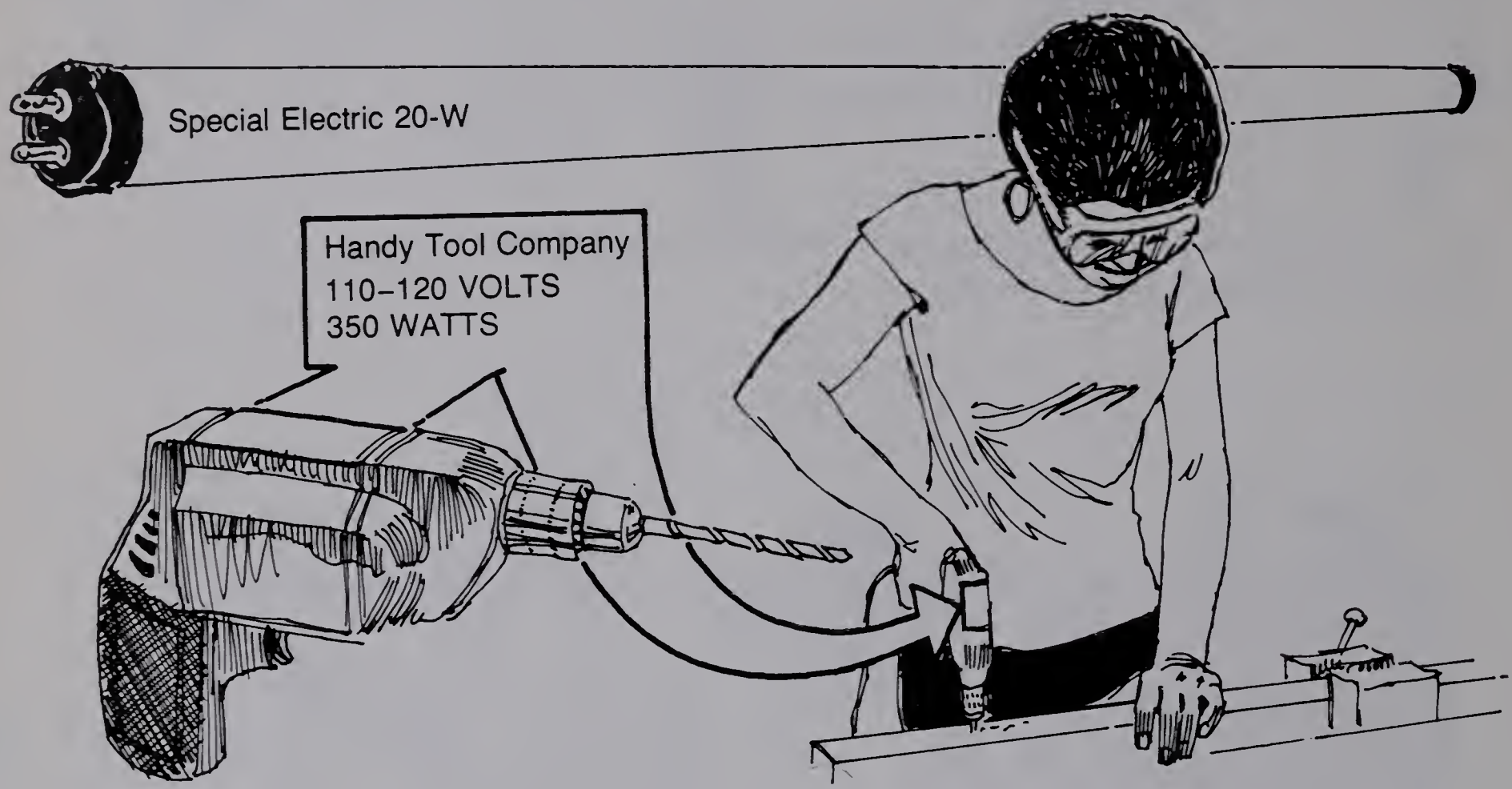
★ **3–15. An air conditioner has a thermostat. How might it be set in summer to save energy?**



Activity 4

House Power

The *watt* is a very common unit of power. Generally wattage is printed on light bulbs and appliances. It tells how fast the light bulb or appliance uses electrical energy.



If you know how fast a car traveled and you multiply by how long it traveled, you can tell how far it went. In the same way, if you know how fast energy was used and you multiply by how long it was used, you find the total energy used.



4–1. How much energy is used by a 100-watt bulb burning for 10 seconds?

A 100-watt bulb isn't a very big energy user, and 10 seconds isn't a long time. So 1000 watt seconds isn't a lot of energy. You need a larger unit for measuring energy in the home.

ONE KILOWATT *is* 1000 WATTS

In an hour, a 1000-watt appliance uses a *kilowatt hour* of energy. That's abbreviated kW h. It's a lot bigger unit than the watt second —3,600,000 times as big! And it's the unit used in the electric meter in your home. Figure 4–1 shows three different electric meters.



Figure 4–1

Check your own meter at home. You may find it is different from those in Figure 4–1. To read the right-hand meter, you simply read the number showing on the face of the meter.

4–2. How many kilowatt hours have been used based on the meter on the right?

Many meters are like the other two shown. They are not easy to read. Look at Figure 4–2.

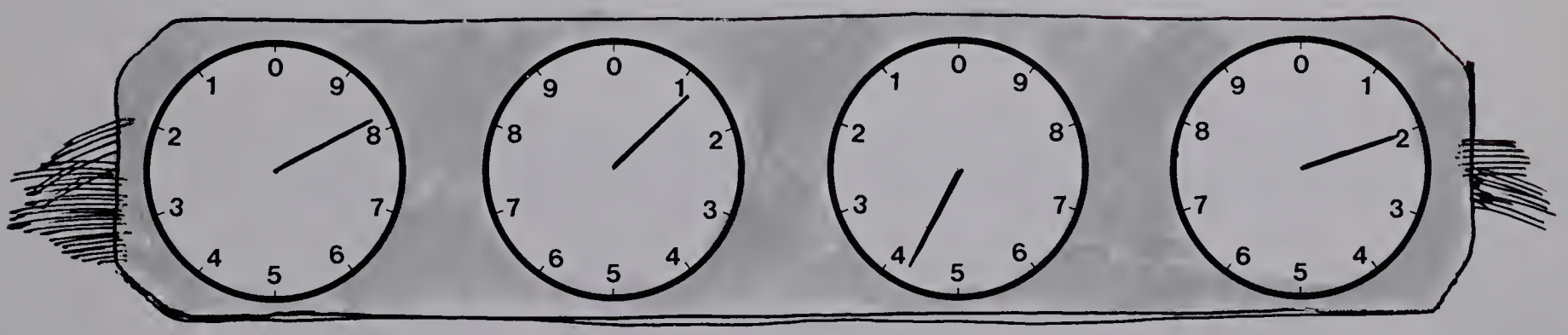


Figure 4–2

4–3. How many kilowatt hours are shown by the four dials in Figure 4–2?

If you got 8142 kW h, consider skipping the rest of this activity.

Do you notice something strange about the dials in Figure 4–2? That's right, every other dial is read backwards! This is because of the way the dials are geared together. The gear wheel of one dial causes the gear wheel of the dial on its left to turn, and so on down the line.

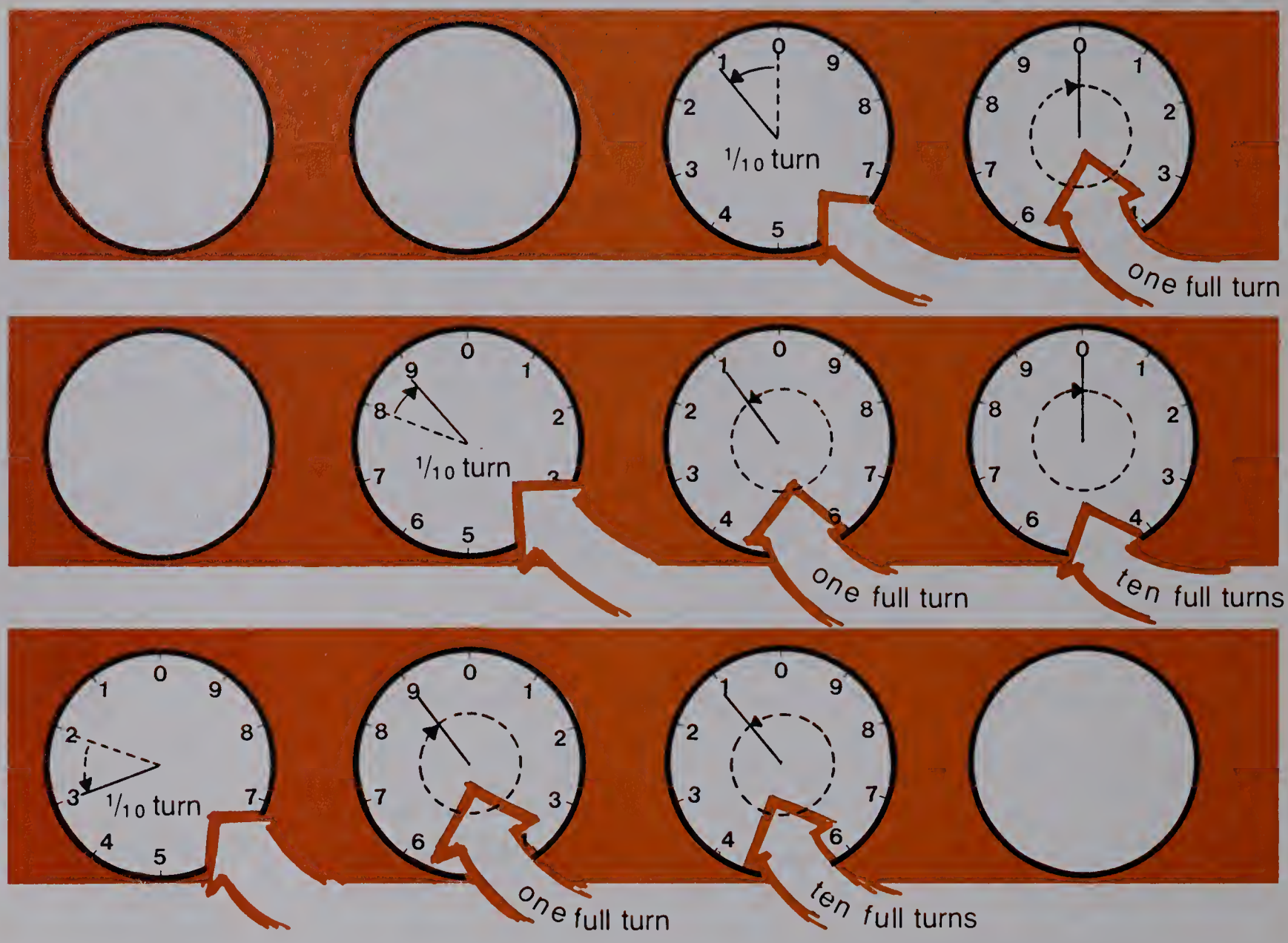


Figure 4–3

What this means is that each dial counts ten times more than the dial to the right. The value of the numerals on the four dials is shown in Figure 4–4.

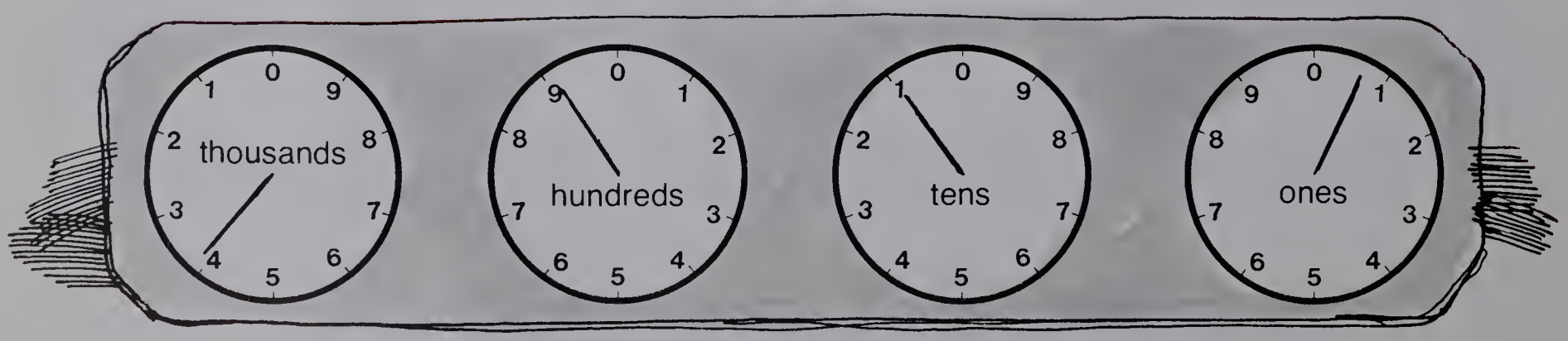


Figure 4–4

4–4. How would you read a dial if the pointer was between the three and the four?

When the pointer is between two numbers on the dial, the reading taken is the lower of the two numbers.

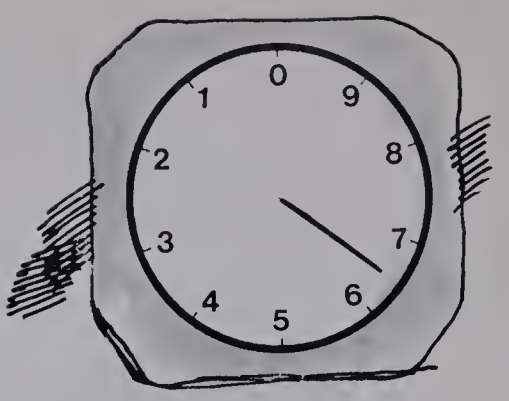


Figure 4–5

4–5. How would you read the dial in Figure 4–5?

4–6. What is the meter reading for Figure 4–4?

Of course, you read the meter dials just as any 4-digit number. Reading from left to right, you get 3 thousands, 9 hundreds, 1 ten and no ones, or 3910 kW h.

Now try another one.

4–7. What reading is shown by the dials in Figure 4–6?

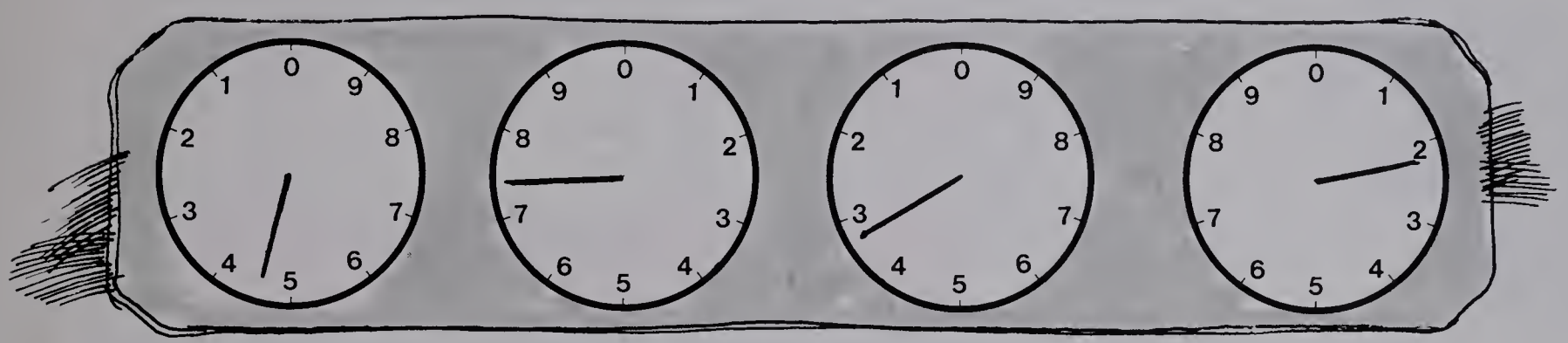


Figure 4–6

After you have answered Question 4–7, turn to the end of this activity to find the correct answer. If you missed, you should go back over the procedure.

If the meter has five dials, as the one shown in the middle of Figure 4–1, then you just read a five-digit number instead of a four-digit number. The same rules apply. Try one.

4–8. What reading is shown by the dials in Figure 4–7?



Figure 4–7

Now that you know how to read a meter you can find out how much electrical energy your family uses in a month. Suppose the electric meter for your home looked like the one in Figure 4–8.

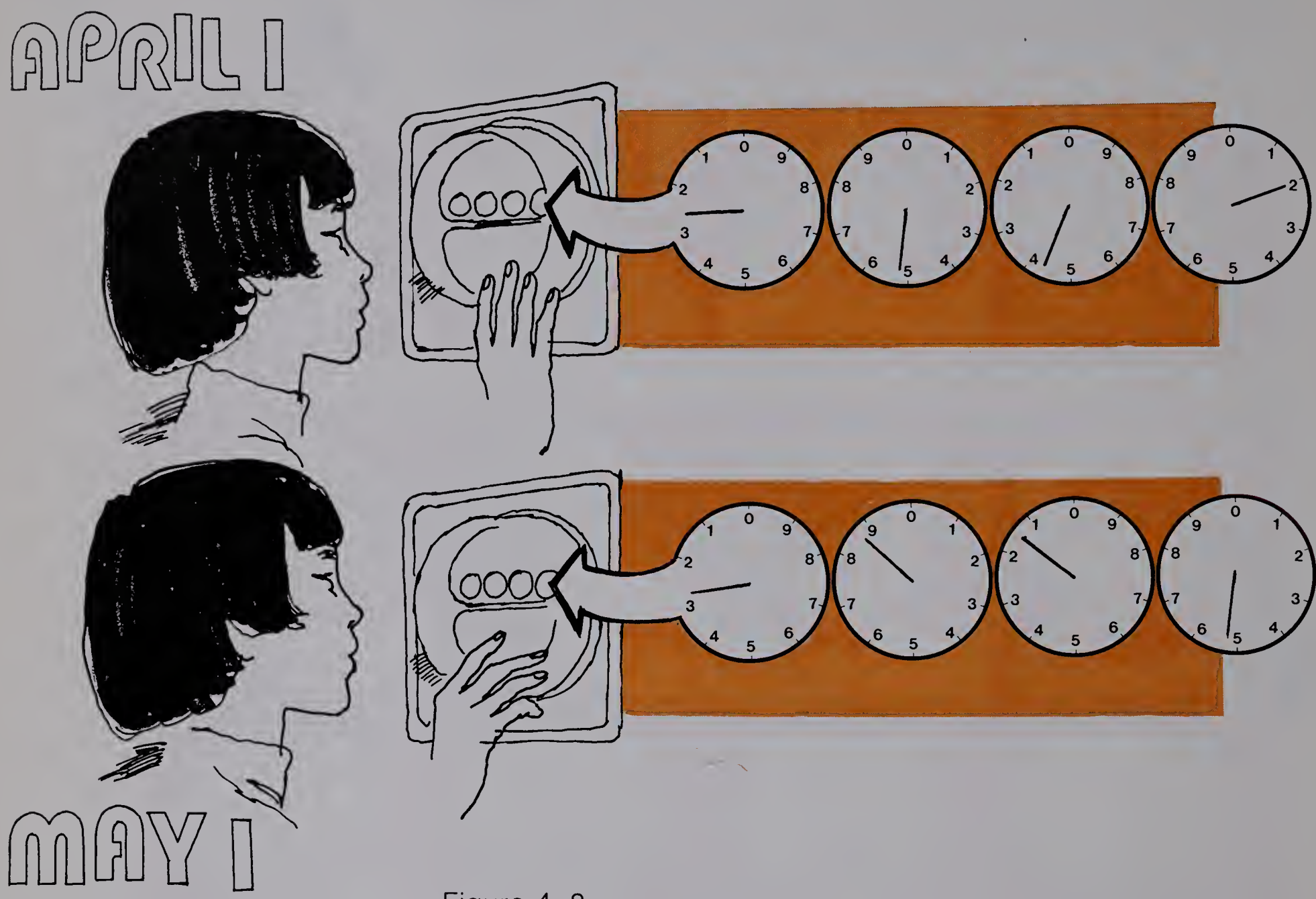


Figure 4–8

4–9. What is the meter reading for April 1?

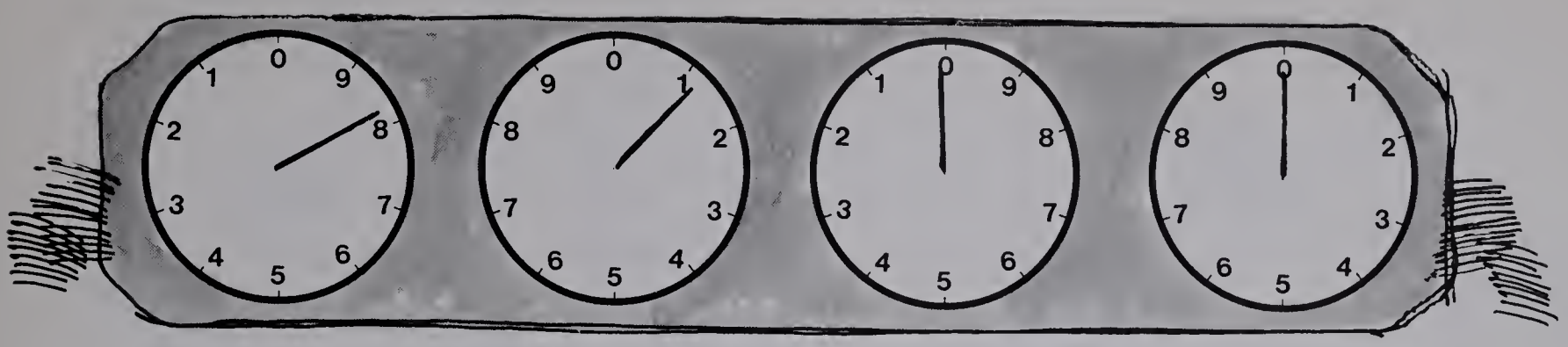
4–10. What is the meter reading for May 1?

On April 1 the meter read 2542, on May 1 the reading was 2815. To find out how many kilowatt hours were used during April, subtract the April reading from the May reading.

2815 reading for May 1
− 2542 reading for April 1
273 kW h used during April

★ **4–11. Using the two electric meter readings in Figure 4–9, how much electrical energy (in kW h) was used between the times the meter was read?**

first reading



second reading

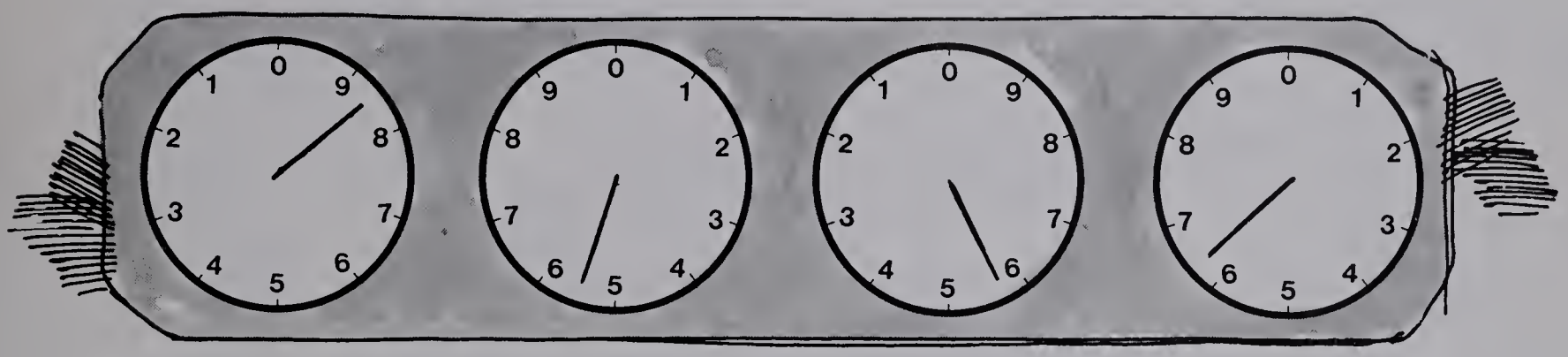


Figure 4–9

Answers

4–7. 4732 kW h 4–8. 35,874 kW h

It's Energy You Pay For

Activity 5



Fuel oil, bottled gas, and gasoline are sold by the gallon. Natural gas is sold by the cubic foot. It's easy to figure the cost of energy from these sources, since it's usually so much a gallon or cubic foot. But electricity is priced differently.

Most electric companies charge a "sliding rate" for electrical energy. The cost per unit goes down as you use electricity. Figure 5–1 shows the sliding rate for electricity charged in a city in Florida.

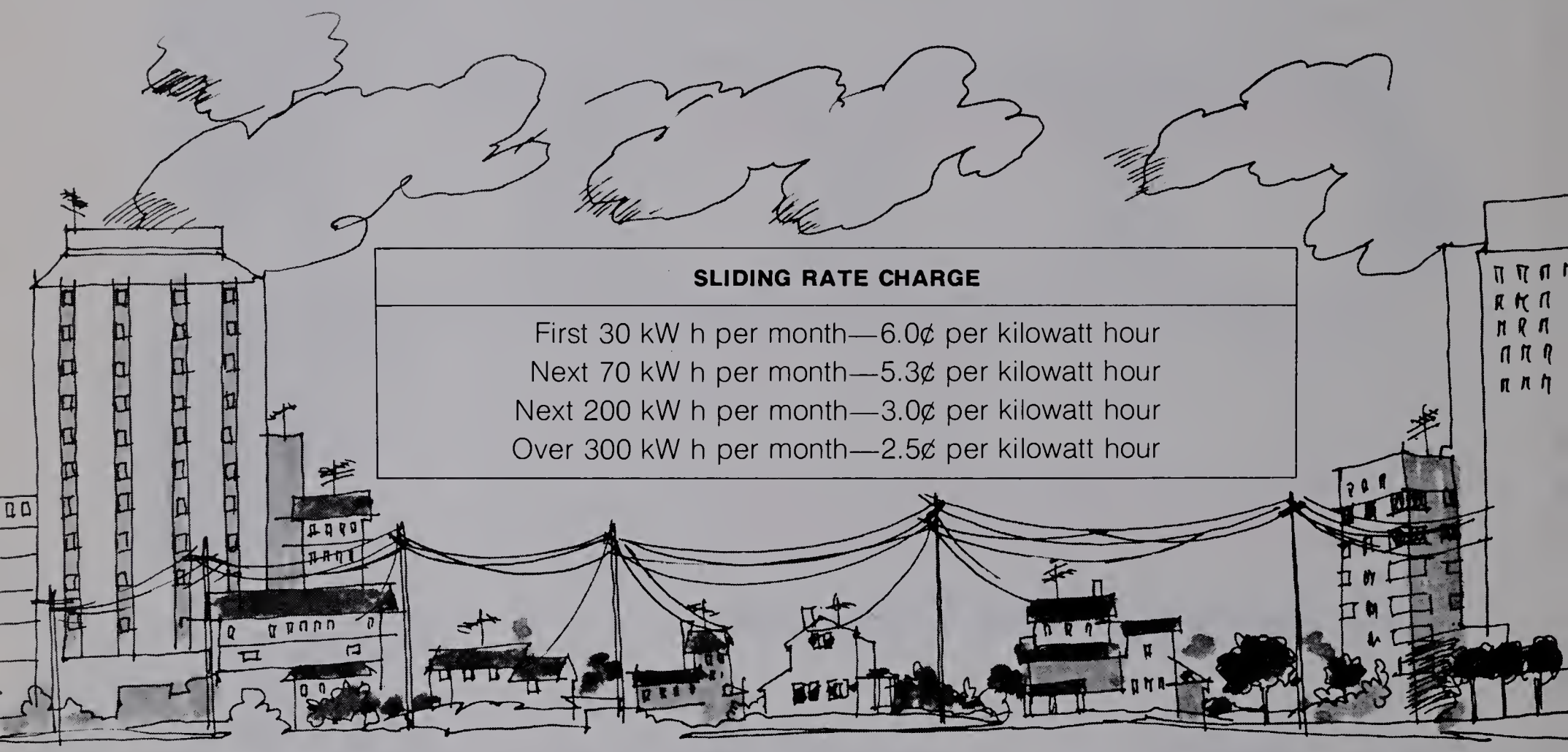


Figure 5–1

Suppose your meter shows that you used 864 kW h during the past month. This is how your bill would be figured:

First 30 kW h	$30 \times 6.0 = \$1.80$
Next 70 kW h	$70 \times 5.3 = \$3.71$
Next 200 kW h	$200 \times 3.0 = \$6.00$
Remaining 564 kW h	$564 \times 2.5 = \$14.10$
	Total for 864 kW h = $25.61

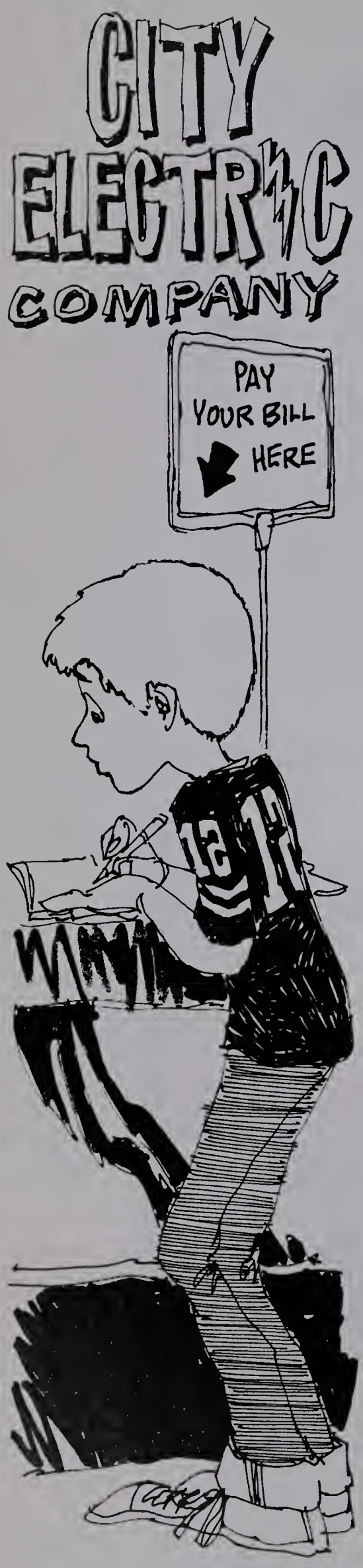
✔ 5–1. Using the rates shown in Figure 5–1, find the bill for a family that used 730 kW h in a month.

Much of the electric power in the United States is generated by using fuel oil or natural gas. But in recent years we've run into trouble. Some of the troubles are shown in Figure 5–2.



Figure 5–2

✔ 5–2. What effect do the four factors in Figure 5–2 have on the amount of fuel oil available and needed for power production?



When supply is low and demand is high, prices tend to go up. Inflation drives prices even higher. Fuel oil prices have increased several times in the last few years.

5–3. How do fuel oil prices affect the cost of electric power?

Many power companies have added a "fuel adjustment" charge to the monthly bill to take care of the increase in fuel prices. It's figured as a percentage of the electrical energy used, or as a certain amount added for each kilowatt hour.

★ **5–4. What reason is given for adding a fuel adjustment charge to the electric bill in some localities?**

In the first example shown in this activity, 864 kW h cost $25.61. If the fuel adjustment charge is 25%, this is how the fuel adjustment charge would be figured.

$$\$25.61 \times 25\% = \$6.40$$
$$\$25.61 + \$6.40 = \$32.01$$

The cost of the electrical energy ($25.61) added to a percentage of this amount ($6.40) gives the total bill ($32.01).

Instead of a percentage, suppose the fuel adjustment charge is one cent per kilowatt hour ($0.01/kW h).

$$864 \text{ kW h} \times \$.01 = \$8.64$$
$$\$25.61 + \$8.64 = \$34.25$$

The cost of the electrical energy by the sliding scale ($25.61) added to the additional charge ($8.64) figured on one cent per kW h (864) gives the total bill ($34.25).

Now put it all together. Start with the monthly meter reading in Question 5–5.

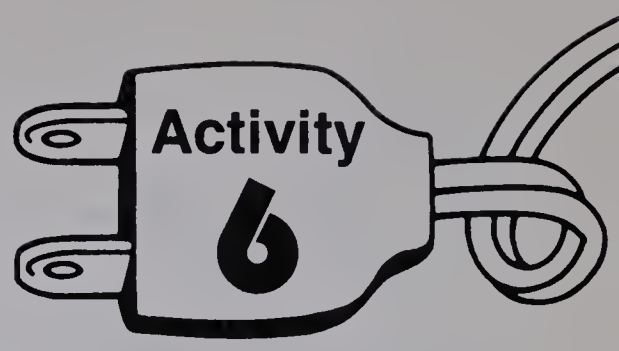
★ **5–5. The March 1 reading on a meter was 5267 kW h; on April 1 it was 5907 kW h. Using the rates shown in Figure 5–1, find the cost of the energy used.**

5–6. If the fuel adjustment charge is 25%, how much is added to the bill?

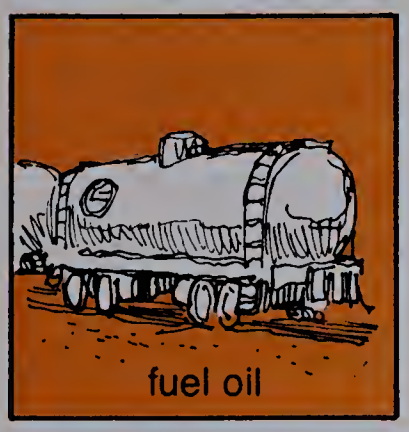
5–7. What is the total bill?

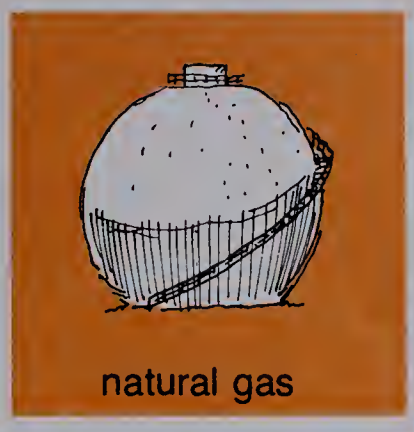
Energy costs. As fuel gets scarcer, it will cost more and more.

Your Money's Worth

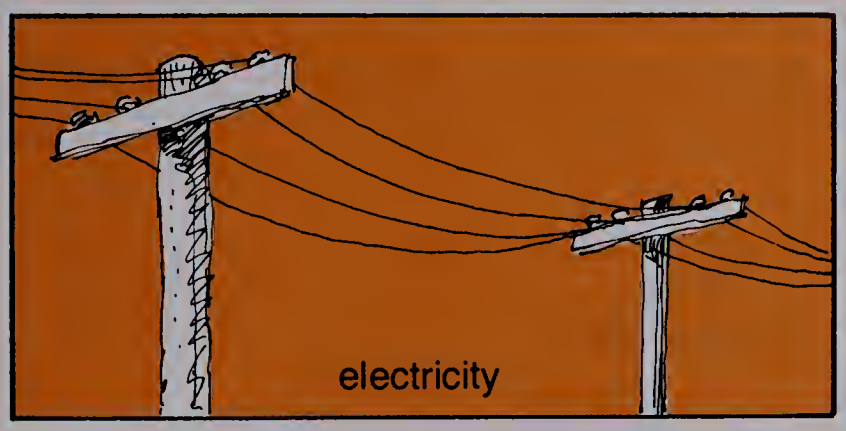


How is your home heated? How you answered depends on how you looked at the question. You might have thought of energy sources such as these—


fuel oil


natural gas

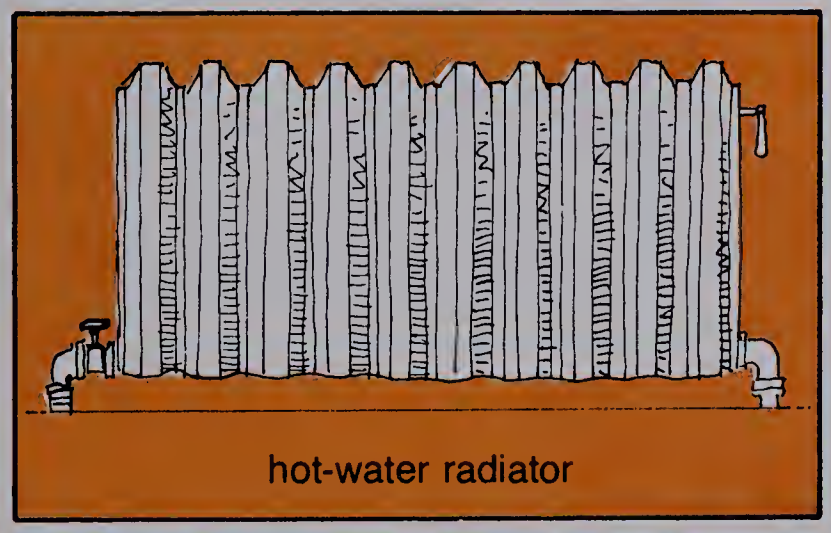

wood

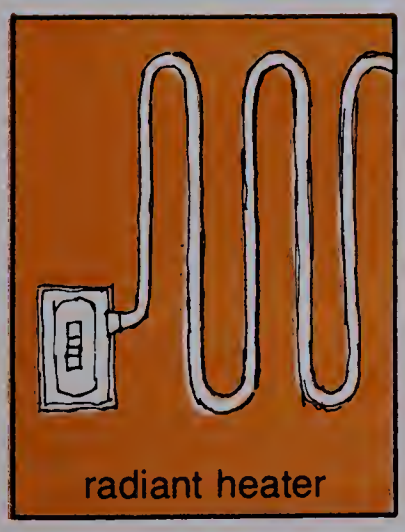

electricity

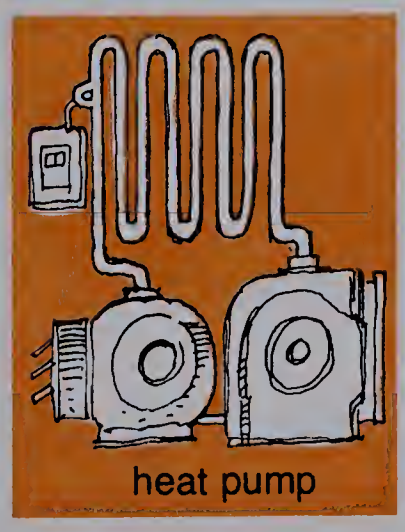

coal

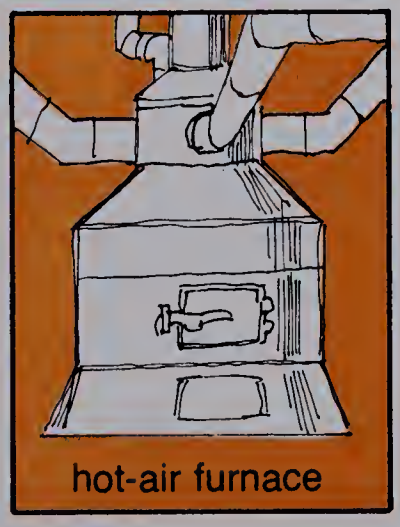
Or you might have thought of heating devices such as these—


stove


hot-water radiator


radiant heater


heat pump


hot-air furnace



You might have been really "scientific" and named convection, conduction, or radiation. These are ways heat is transferred.

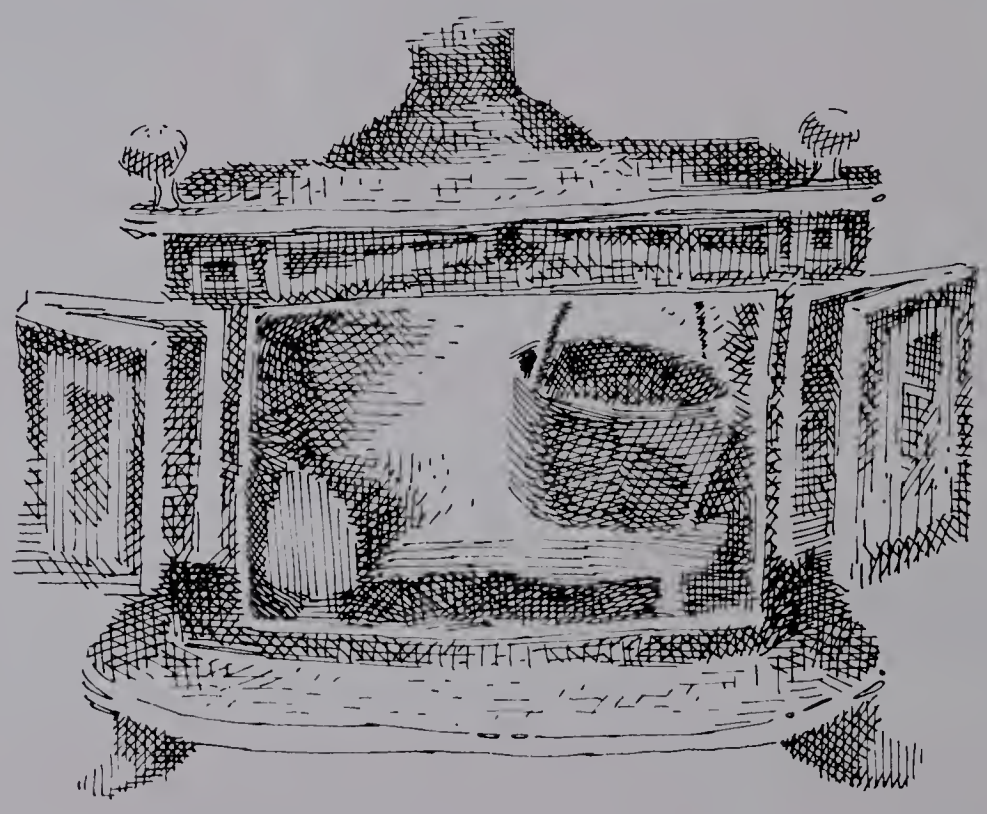
Of course, if you live far enough south, you might have said "no way." You get all the heat you need from the sun.

In this activity, methods of home heating will refer to the energy source. The five principal sources are fuel oil, natural gas, electricity, coal, and wood.

✔ 6–1. Which energy source is used to heat your home?

Of the five principal sources, four depend on burning the fuel in a firebox connected to a chimney. The poisonous gases from the burning fuel are kept separate from air that is used to heat the building. On the other hand, keeping them separate means that heat cannot be transferred as well.

✔ 6–2. What is there about gases from burning fuel that requires them to be kept separate from the air that heats a building?



✔ 6–3. What's different about the products from burning wood and coal as compared to those from burning fuel oil and natural gas?

Once, just about all home heating was done with wood or coal. But these two fuels aren't as convenient to use as fuel oil and natural gas. They leave ashes that must be removed, and they don't flow into the firebox.

★ 6–4. Of the five principal energy sources for home heating, which two are not used as much as they used to be?

When homes are heated by electricity, heating coils may be used. The coils can be in separate radiant heaters, as in Figure 6–1, or in units built into the floors or walls.

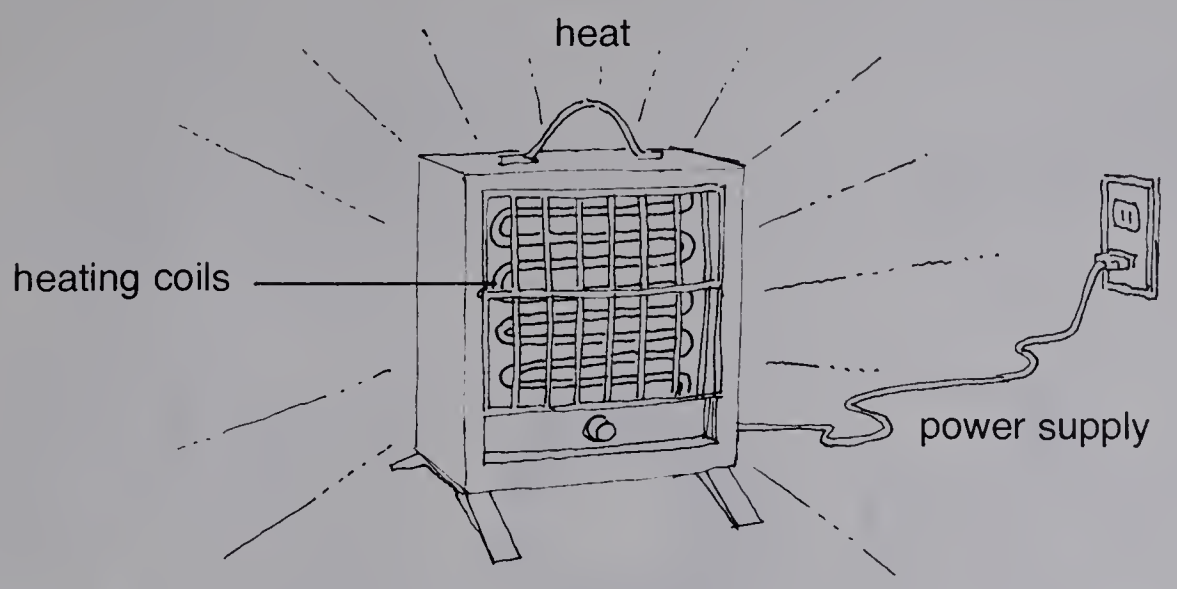


Figure 6–1

✔ 6–5. What advantage do you think electricity has over burning fuels?

Another way homes may be heated by electricity is a little more complicated. It involves a device called a *heat pump* (Figure 6–2).

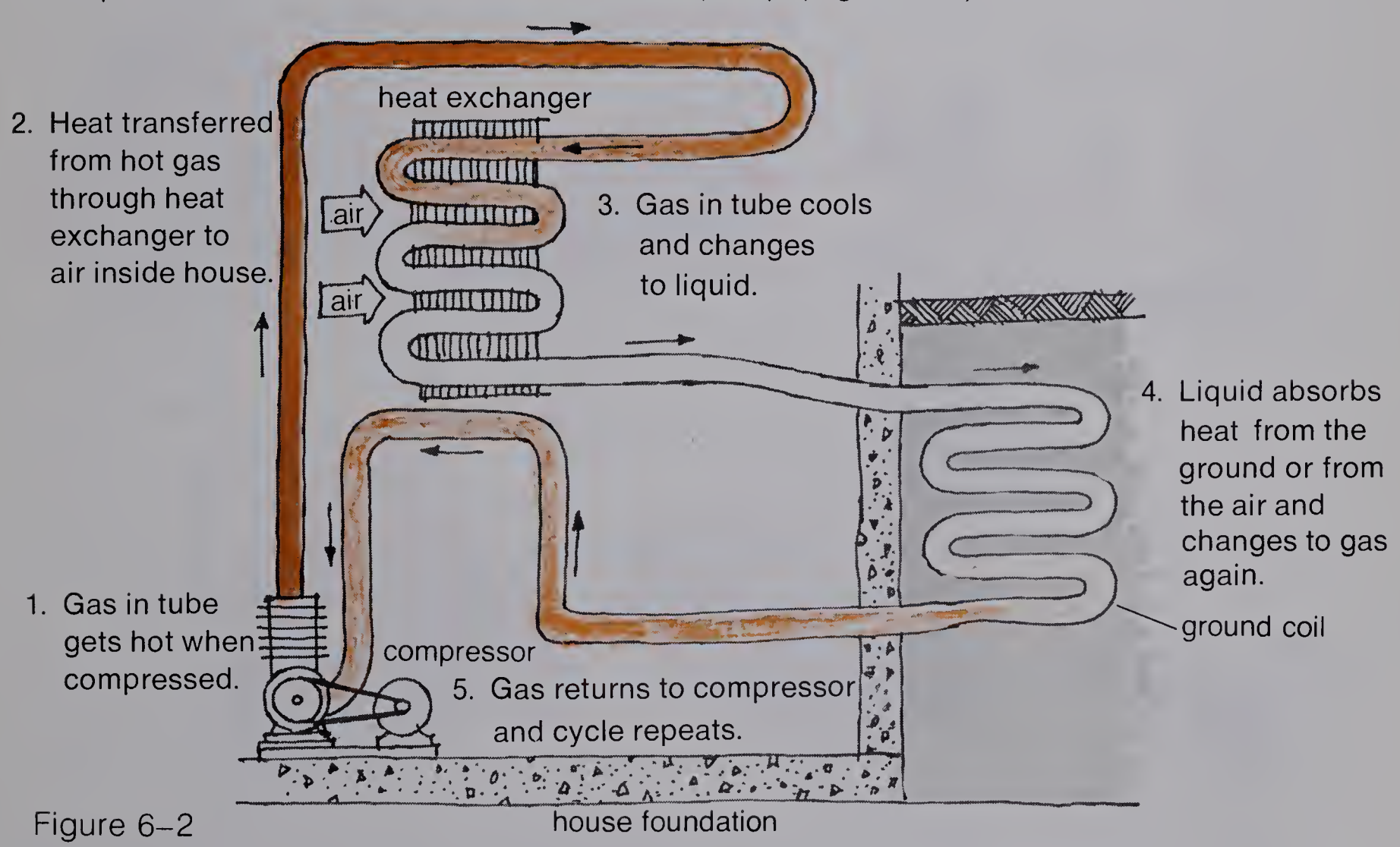


Figure 6–2

✔ 6–6. How is heat transferred from the heat pump to the house?

Energy Cost

What about the cost of fuels that are used for heating? Which energy source do you think provides the most energy for each dollar spent? When you're paying for energy, you want to get your money's worth.

Comparing the energy from different sources is something like adding apples and oranges. You need a common unit to make comparisons.

Btu C kWh

Suppose kilowatt hours is chosen as the common unit. Then the cost of a kilowatt hour of energy from each source can be compared. But, there's another thing to consider. Not all the energy removed from a source is useful energy. Look at Figure 6–3.

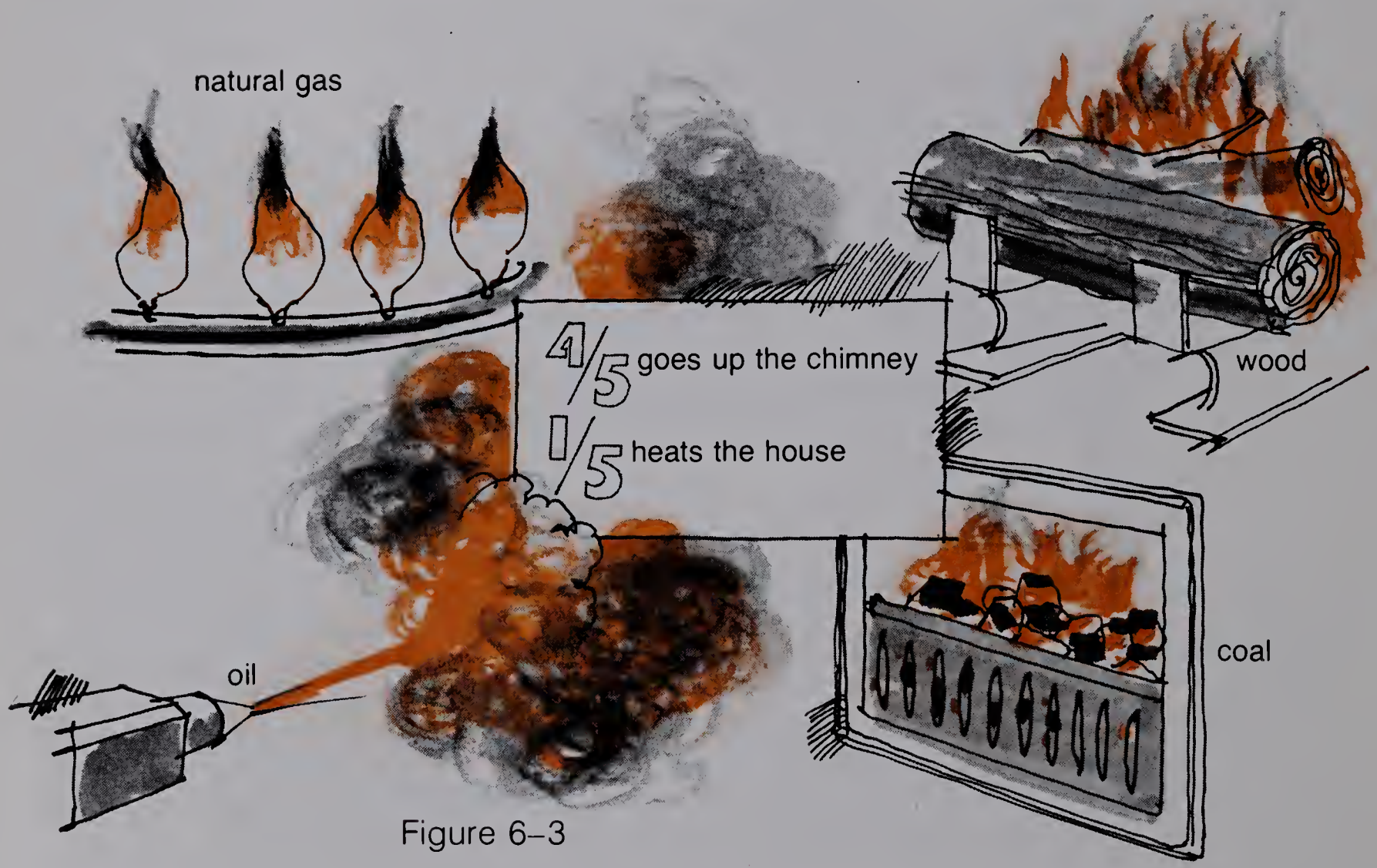


Figure 6–3

With the electrical energy, however, the figures are the other way around. About $^4/_5$ of the energy used in an electric heater is useful energy. Only about $^1/_5$ is wasted.

Figure 6–4 compares the cost of heat energy from various sources. The energy units for all the sources have been changed to kilowatt hours. The right-hand column gives useful kilowatt hours per dollar.

COST OF HEAT ENERGY FOR HOMES

ENERGY SOURCE	COST	TOTAL KW H PER DOLLAR	USEFUL KW H PER DOLLAR
Fuel oil	35¢ per gallon	114	23
Natural gas	0.3¢ per cubic foot	93	19
Household electricity	4¢ per kW h	25	20
Coal	$46 per ton	180	36
Wood	$46 per cord	138	28

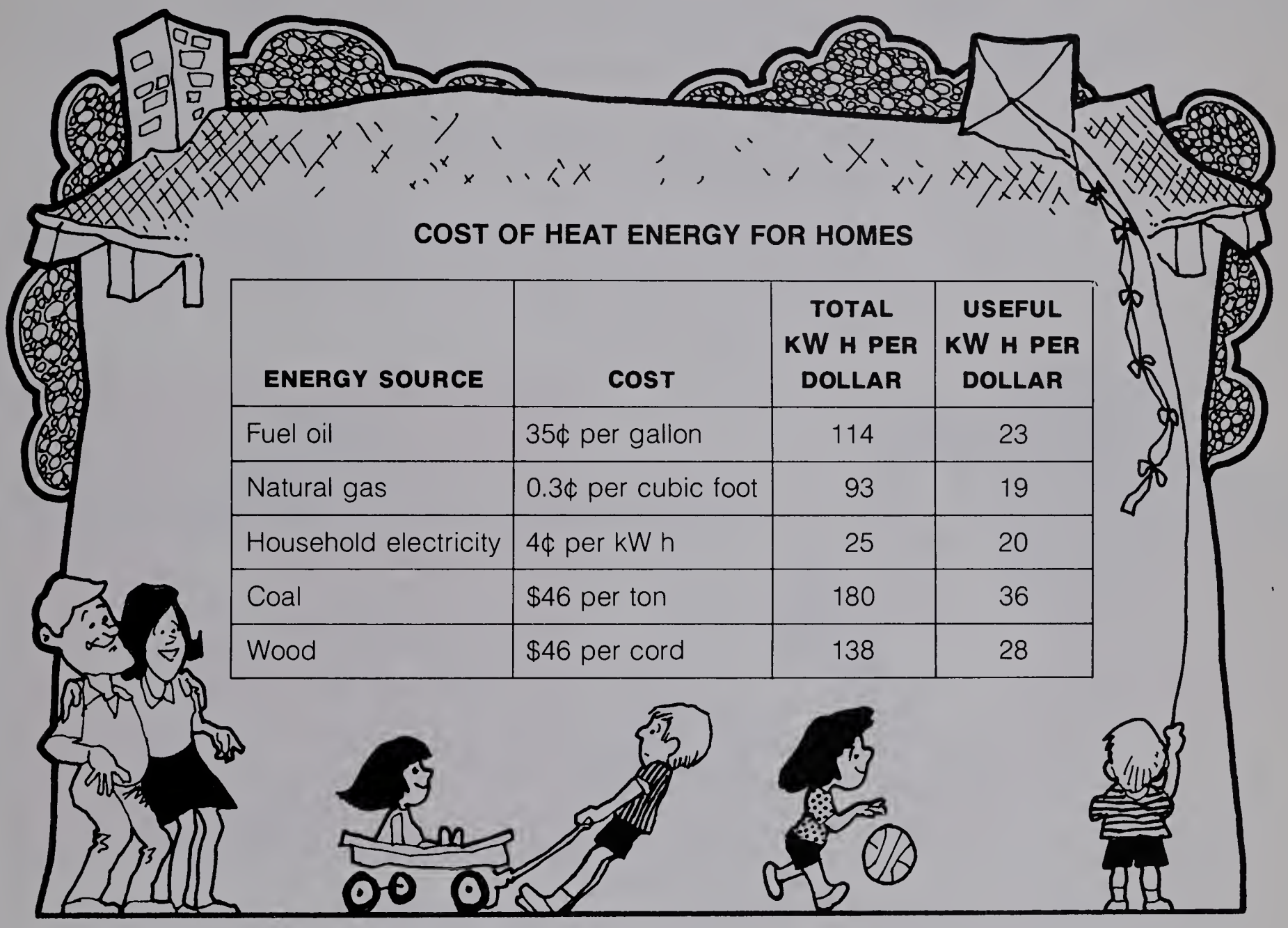


Figure 6–4

✔ 6–7. Why is it necessary to list all the energy sources in kilowatt hours per dollar?

✔ 6–8. Why is there such a big difference between the total energy per dollar and the useful energy per dollar for the fuels?

✔ 6–9. Of the five energy sources listed, which one gives you the most useful energy for your dollar? Which gives you the least?

Of course, these prices are changing all the time, and they're different in different localities. You may have prices much higher than those shown in the table. But you can still compare to see if you're getting your money's worth.

Activity 7

Constant Temperature

Your body temperature holds pretty constant at about 37°C (98.6°F). Night or day, summer or winter, it doesn't change very much—unless you're sick or something is wrong in your body.

✔ 7–1. What generally happens to your body temperature when you are ill?

Because people's bodies are at a constant temperature, most people feel more comfortable if their surroundings are kept at a constant temperature also.



If your body loses heat easily to the surroundings, it's too cold. You shiver and shake.



If your body has a hard time losing heat to the surroundings, it's too hot. You perspire.



✔ 7–2. At about what temperature do you feel most comfortable in your home?

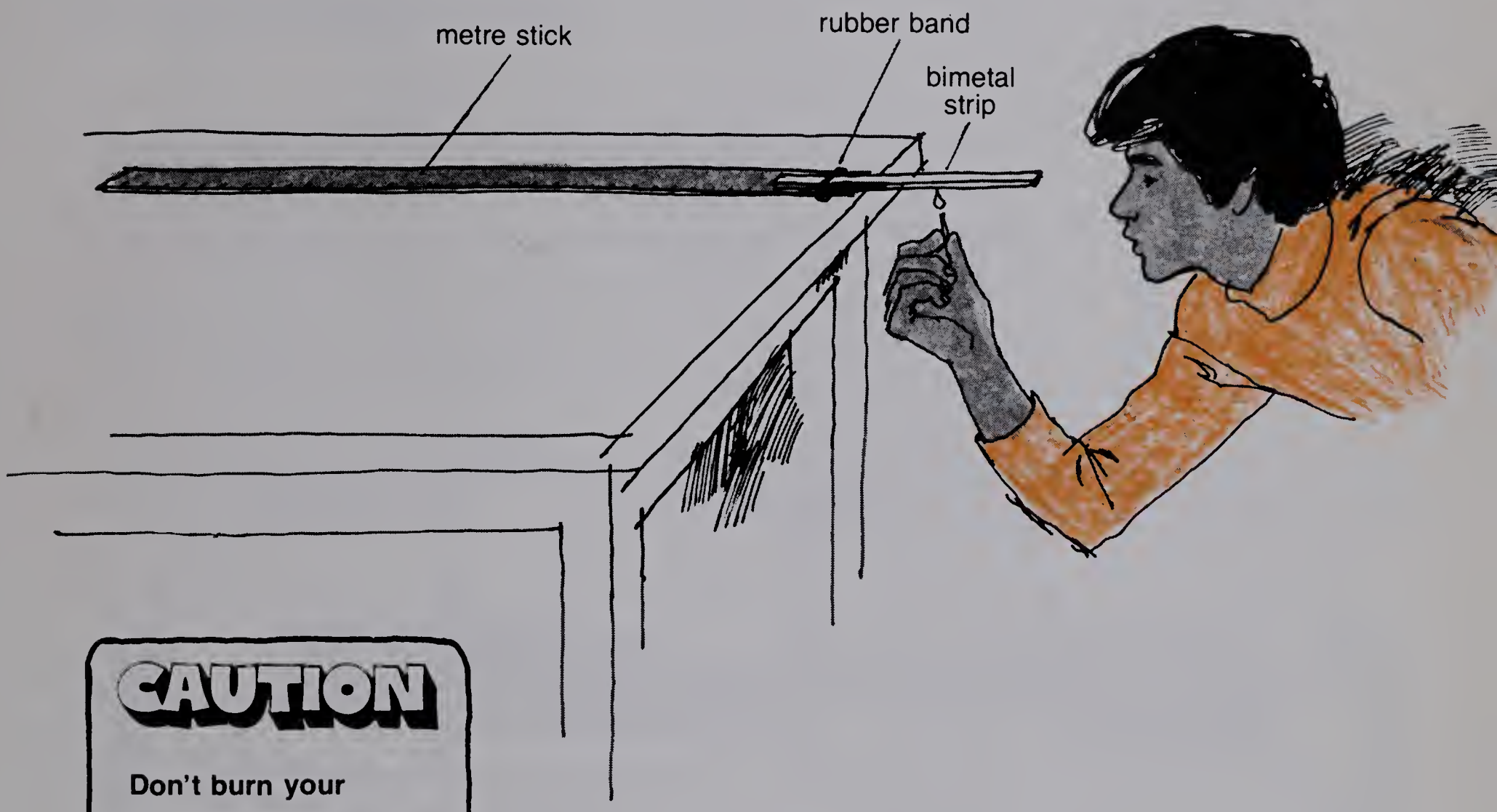
You probably gave some temperature from 18°C to 24°C (65°F to 75°F). Different people feel comfortable at different temperatures. A person may be comfortable at a certain temperature at one time and at some other temperature at another time. But regardless of the temperature you gave, there are times when you have to do something to maintain it. Sometimes you have to add heat; other times you have to take heat away.

Most air-conditioning and heating systems are controlled by thermostats. That means you set a thermostat at the temperature you want, and the system is turned on and off to keep that temperature.

How does a thermostat work? To find out you will need the following:

bimetal strip
rubber band
metre stick
desk or table
match

A. With a rubber band, attach the bimetal strip to the metre stick as shown. Place the metre stick on a table or desk so that the bimetal strip is horizontal.



CAUTION

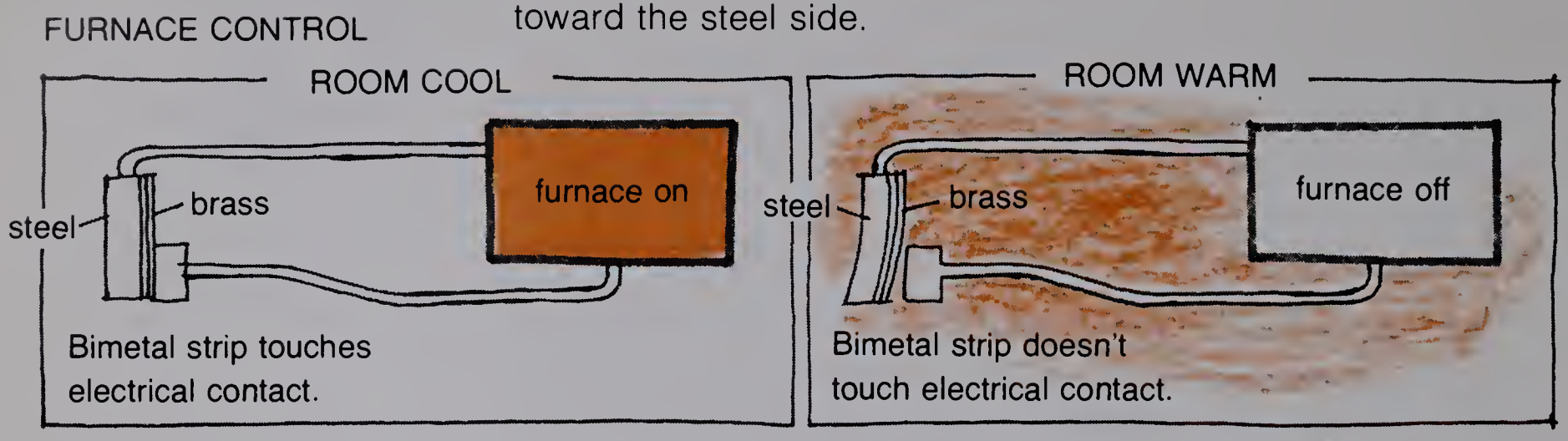
Don't burn your finger in Step B.

B. Put your eye at the same level as the bimetal strip. Light a match and hold it under the center of the strip for a few seconds. Put out the match. Continue to watch the bimetal strip as it cools.

7–3. What happens to the bimetal strip as it heats?

7–4. What happens to the bimetal strip as it cools?

A bimetal strip is often made of brass and steel. Brass expands and contracts faster than steel, so heat makes the strip bend toward the steel side.



7–5. What happens when the room warms up?

7–6. What happens as the room cools?

A thermostat can be used to control a heating system. The result is that the temperature in the house stays about the same all the time. A lot of manufactured and living things are self-controlling. Scientists call this kind of self-control *feedback control.*

Feedback is a very important part of all automatic heating systems. Figure 7–1 shows how feedback works in a heating furnace. Start at the upper left and follow the arrows.

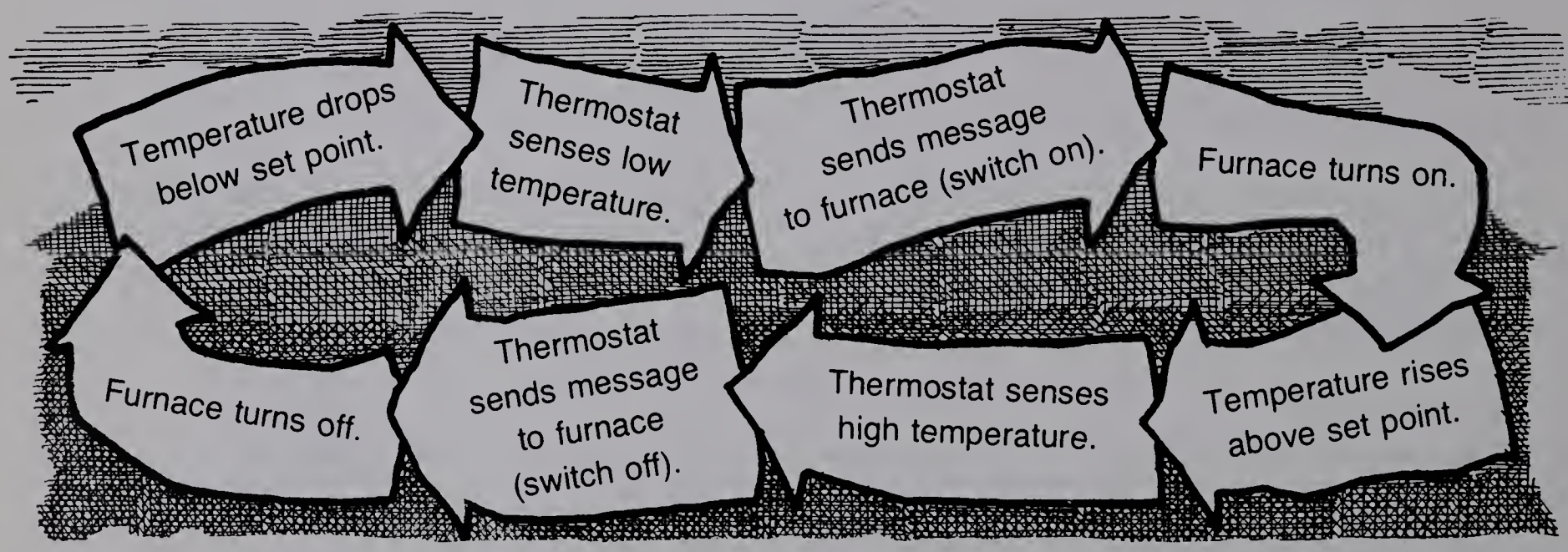


Figure 7–1

A thermostat on an air conditioner works the same as one on a heating system. It controls the operation of the air conditioner by opening and closing a contact.

★ **7–7. On an air conditioner, is the electrical contact made when it is too warm or too cold?**

✔ 7–8. In your notebook, make a sketch like that in Figure 7–1. Use the blanks to show how a thermostat switches an air conditioner on and off to keep the temperature at a set point. Start by filling in the upper left box with "temperature rises above set point." Then fill in the other boxes.

If this is the first time you have run into feedback control, don't worry if its meaning isn't completely clear. You will see it again in other minicourses. However, if you have seen it before and you're still not sure you understand it, you may want to take a look at *Resource Unit 13.* It describes feedback control in more detail.

Staying Comfortable

The same house is shown in two situations below. Suppose the "comfort temperature" in each case is 21°C (70°F).

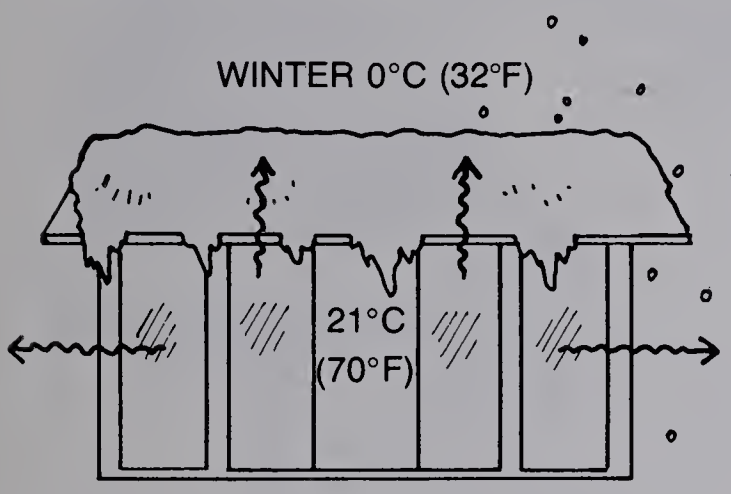


Figure 7–2

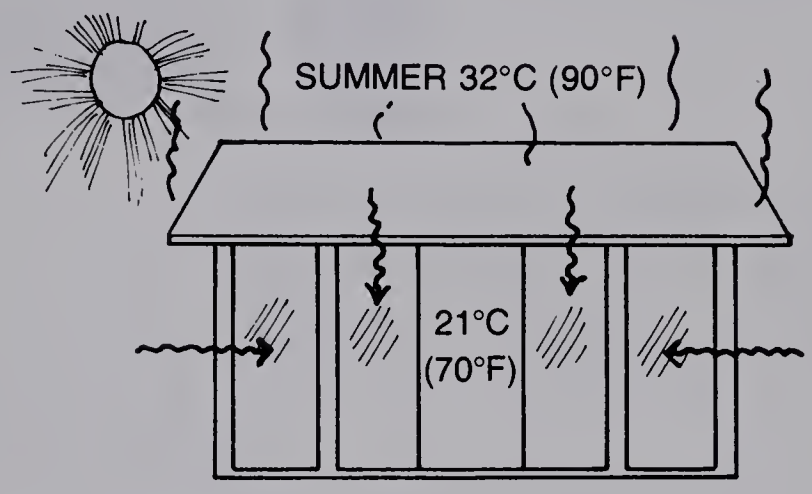


Figure 7–3

✔ 7–9. What is the temperature difference in Figure 7–2?

✔ 7–10. What is the temperature difference in Figure 7–3?

In winter, heat inside the house is lost to the colder outside air. In summer, heat is gained from the hotter outside air. The greater the temperature difference, outside to inside, the greater the amount of energy used by the heating or cooling system to keep the inside temperature constant.

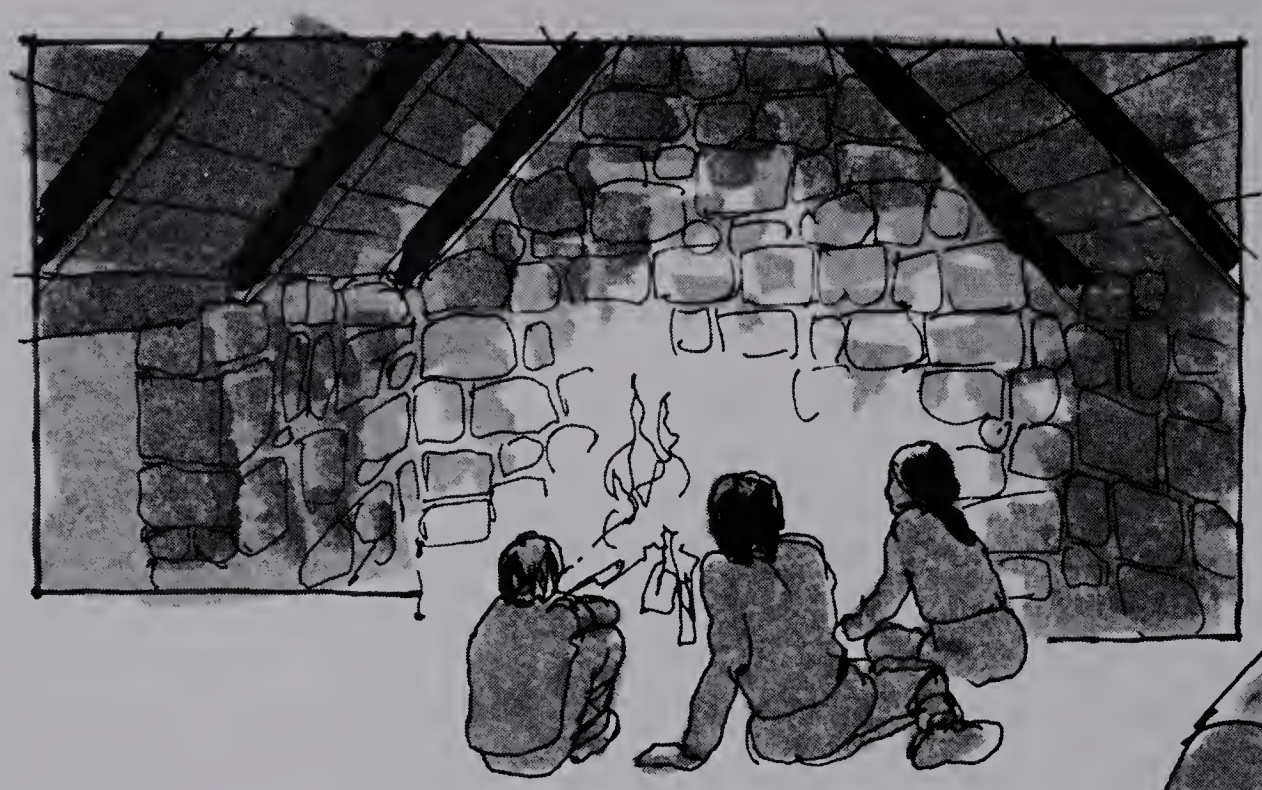
★ **7–11. Suppose you set the thermostat lower and decrease the time the heating system is on by a third. What effect will this have on the energy used?**

Staying comfortable takes energy. That's true whether you have to add heat to stay warm or take away heat to keep cool.

Activity 8

Keep Cool

People have used heat in their homes for centuries.





First simple fuels like wood, peat, and coal were burned in the middle of living rooms. Now, fuels like natural gas, fuel oil, and electricity are used for stoves, furnaces, radiant heaters, and heat pumps.

Only recently have people been able to cool their homes.





Before air conditioning, people sweltered when it got hot, or they moved, at least temporarily, to cooler places.

Today we take air conditioning for granted, but even keeping foods cool was not easy in the past. The ancient Egyptians cooled their drinking water and other beverages by evaporation (Figure 8–1). An "ice box," like that in Figure 8–2, depended on ice that was cut from lakes in the winter.



Figure 8–1

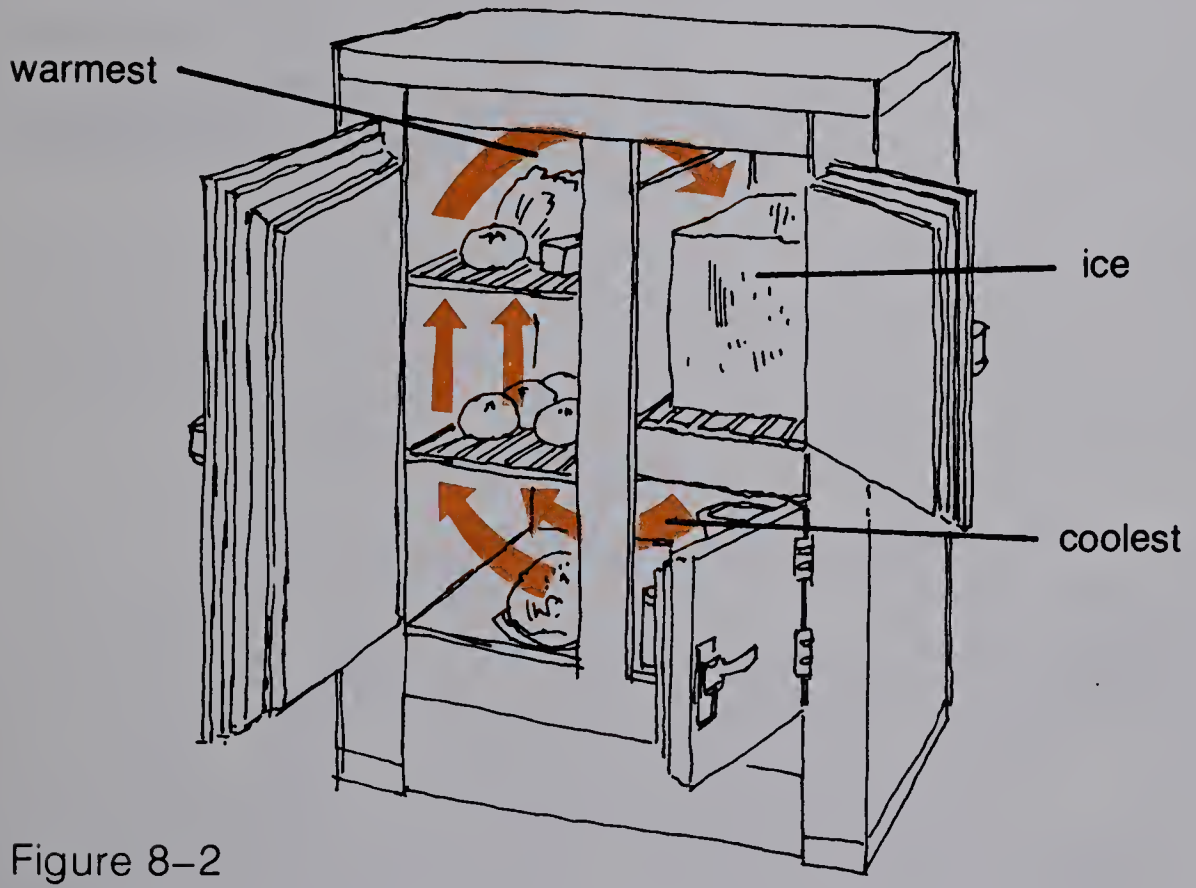


Figure 8–2

✔ 8–1. Why wouldn't the primitive cooling in Figure 8–1 be effective on very humid days?

✔ 8–2. What important by-product of the ice box had to be taken care of regularly?

Electric refrigerators and air conditioners are similiar in operation. In most cases a substance called *Freon* is used as the refrigerant. Figure 8–3 explains both devices.

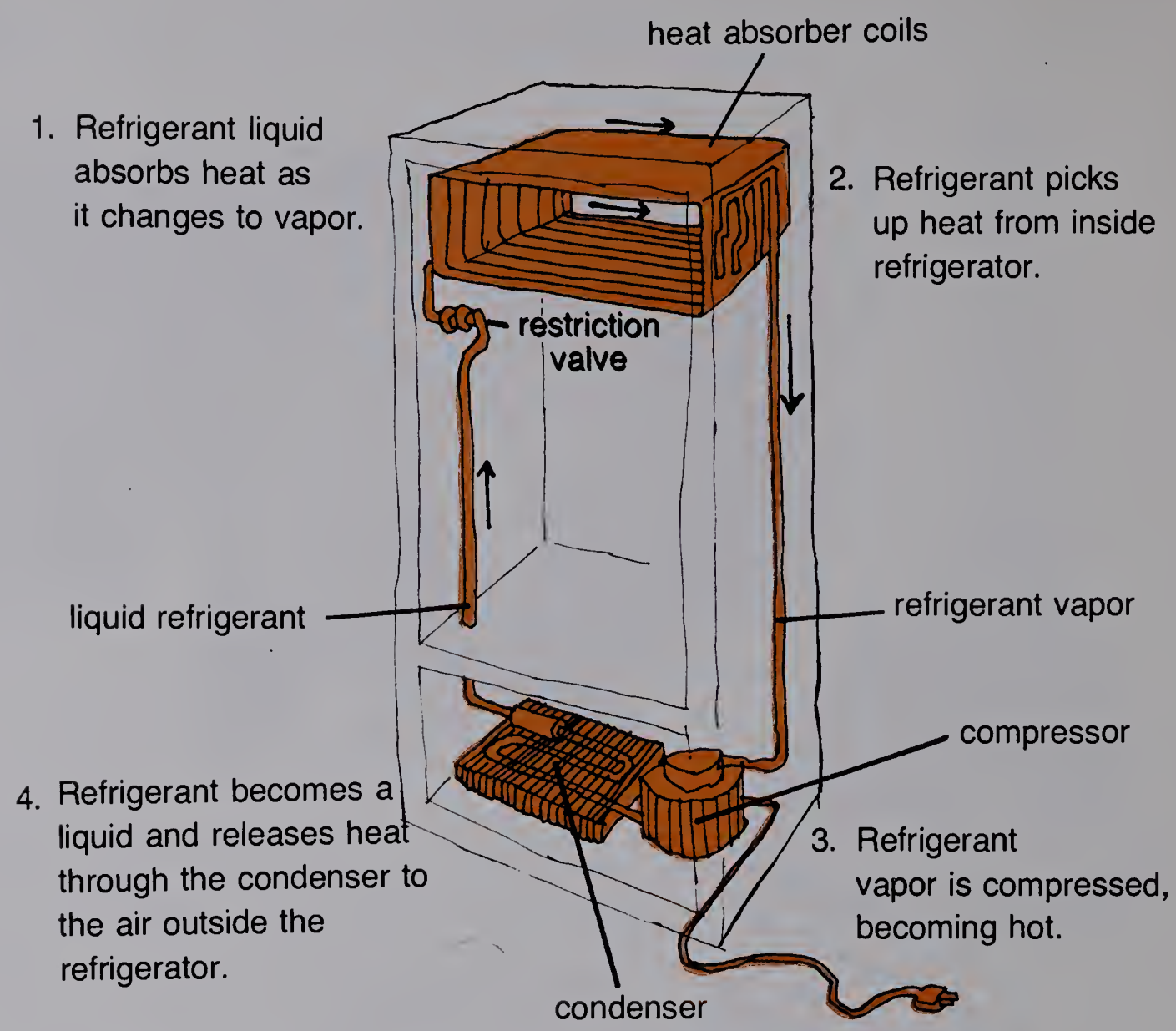


Figure 8–3

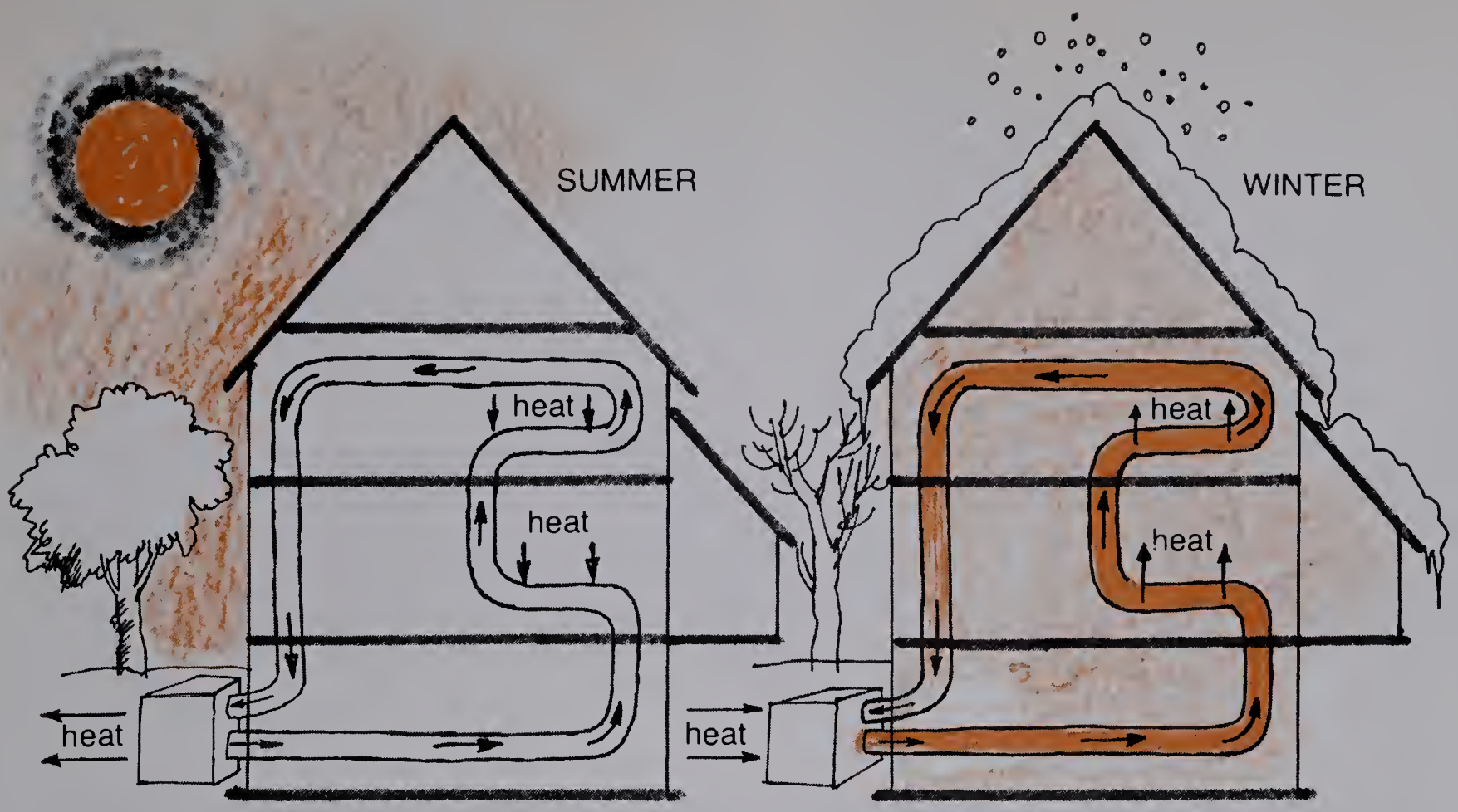
You can see that the refrigerant is condensed or expands, releases or absorbs heat. That's the way cooling occurs—heat is absorbed from one place and released to another.

★ **8–3. In a refrigerator what happens in the**
a. compressor?
b. condenser?
c. absorber?

8–4. In an air conditioner, where does the refrigerant get the heat that it carries to the outside?

8–5. Explain why you can't cool the kitchen by keeping the refrigerator door open.

Some modern heat pumps can do double duty. They are air conditioners in the summer and heaters in the winter.

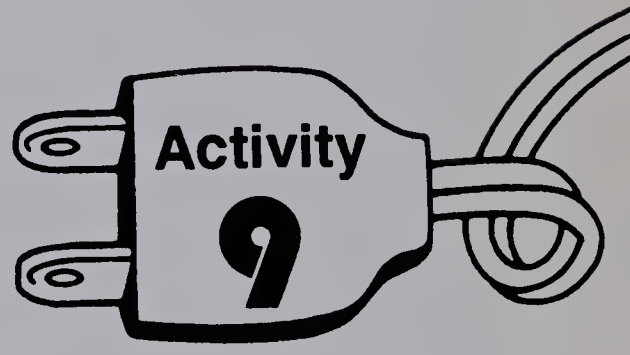


Heat from compressing the refrigerant is released outside, while heat is picked up inside.

Heat from compressing the refrigerant is released inside, while heat is picked up outside.

8–6. Where is the air cooled in an air conditioner?

Cutting Energy Costs



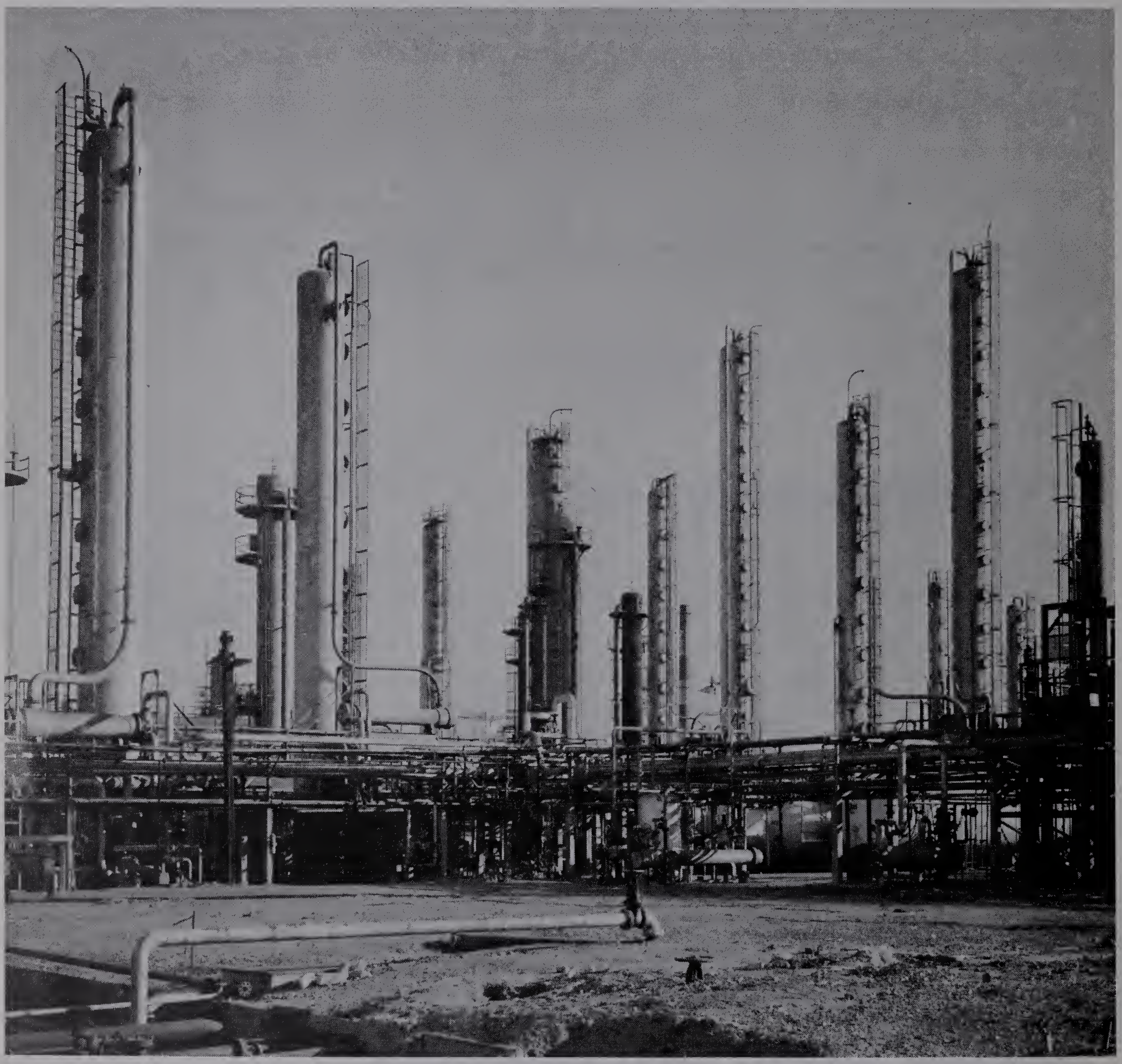
What is the monthly bill for utilities in your household? Amounts between $30 and $80 a month are quite common. That adds up to a lot of money in a year.



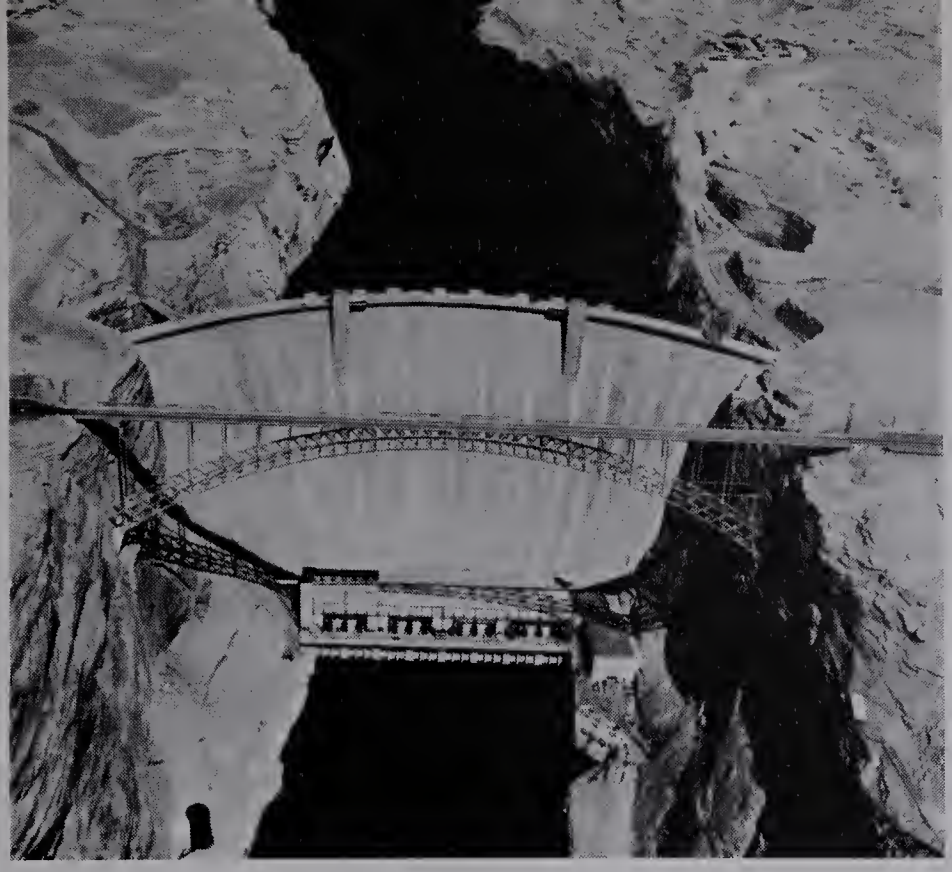
The cost of energy is likely to keep going up. The money you spend buying energy is money you can't spend on something else. Keeping your home either warm or cool takes about half of the total energy used by your family.

9–1. How do you think energy can be saved at home?

9–2. Where do we get energy?



Natural gas, fuel oil, gasoline, and heating oil are among the products from a refinery.



Hydroelectric generators provide much of the electric energy used in some areas.



Once, wood was the principal source of energy for heating and cooking.



There are still huge reserves of good quality coal in the United States.

Most of the energy we use today comes from our natural surroundings. It is possible to use up this type of energy. Knowing how to keep certain things cool and other things warm will help prevent an energy shortage.

In summer, an air conditioner can cool the inside of a house. It moves heat out. But heat keeps getting back into the house, through the walls, windows, and roof as shown in Figure 9–1.

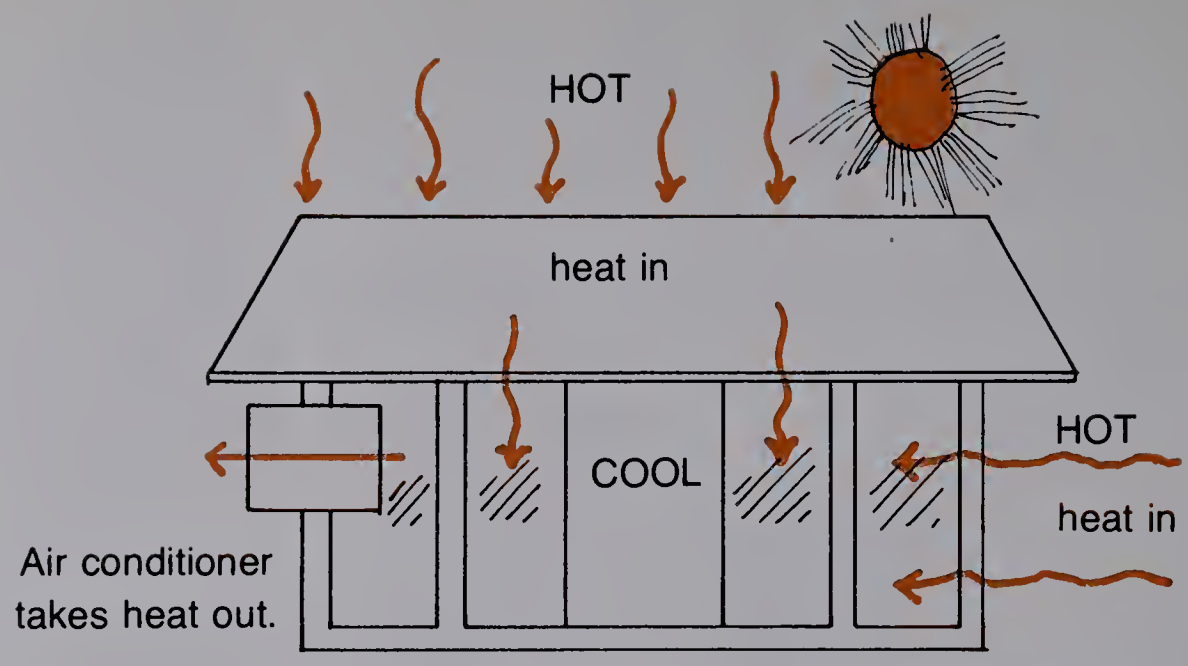


Figure 9–1

In winter, a heater puts heat energy into the house. But, all the time, heat energy gets out of the house. It leaves through the walls, windows, floors, and roof as shown in Figure 9–2.

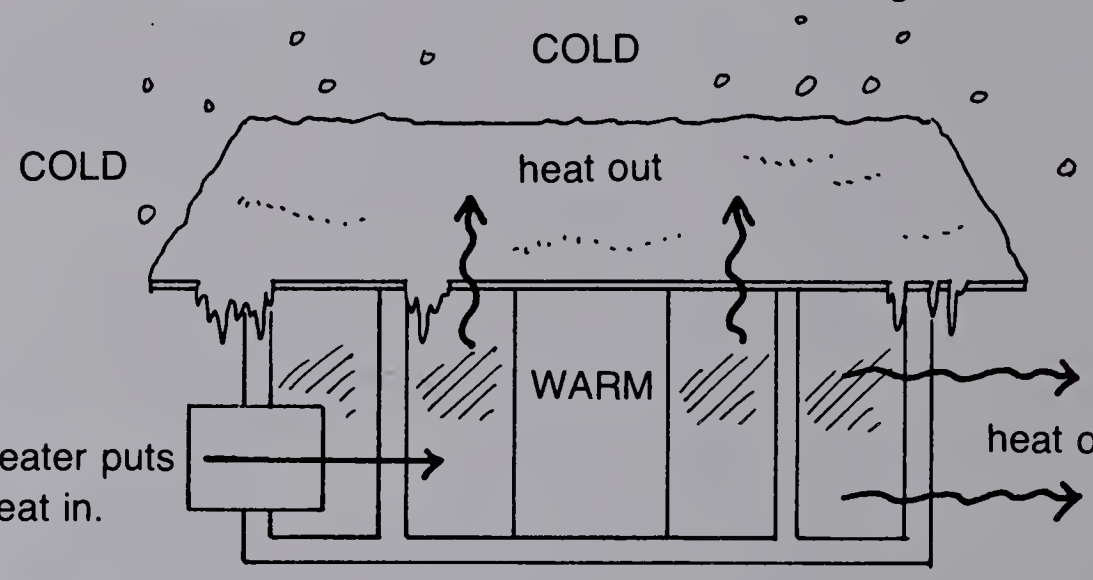


Figure 9–2

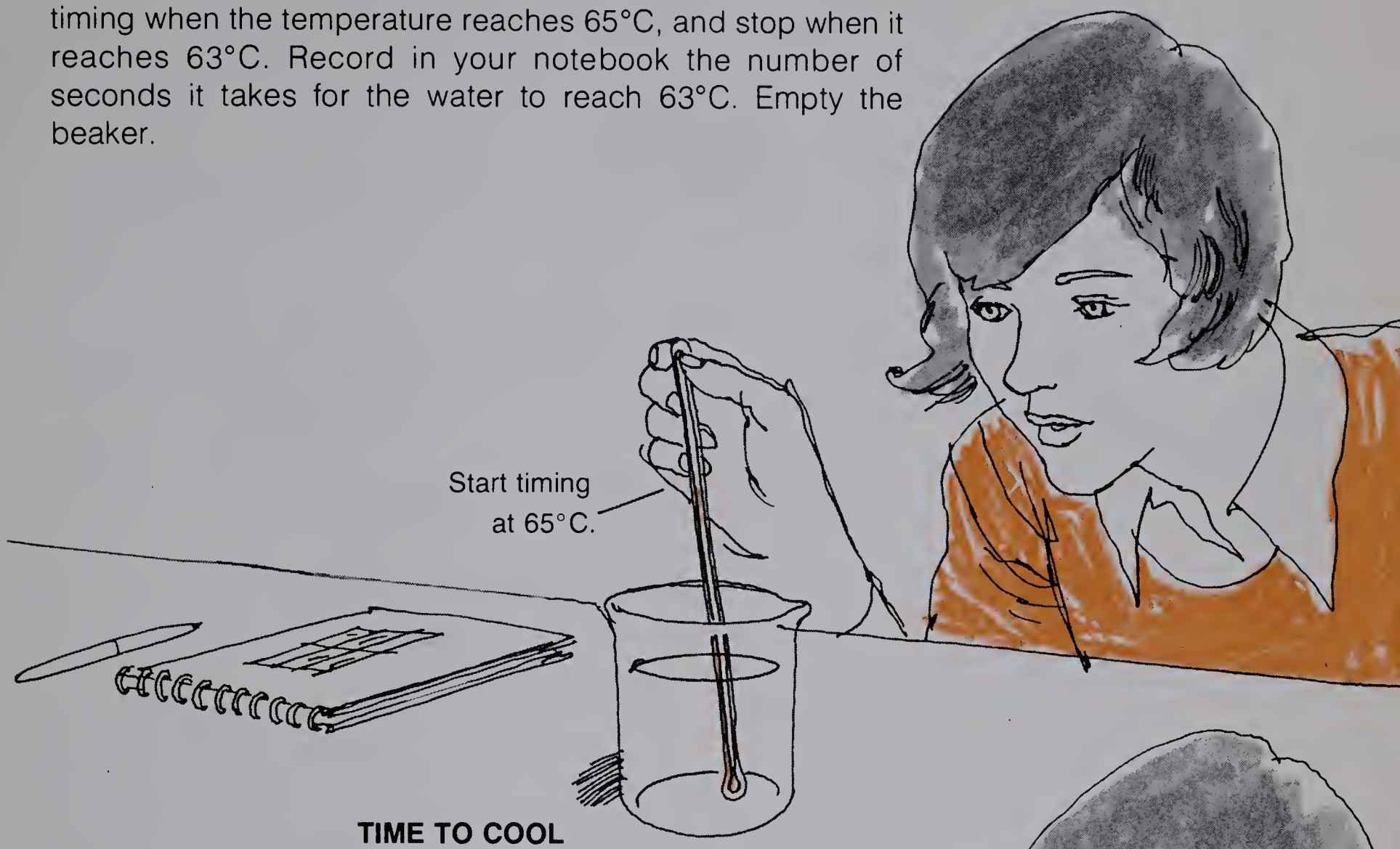
9–3. What is an obvious way to cut heating and cooling bills?

This investigation may give you some clues about how heating and cooling bills can be cut. You will need 30 minutes and the following:

beaker, glass, 250-ml
thermometer, 0–110°C
watch or clock with second hand
small piece of plastic foam, 10 cm × 10 cm
small piece of plastic foam with hole in center, 10 cm × 10 cm
cloth or paper towel

Be sure you know how to use the thermometer. If you aren't sure, see *Resource Unit 14* now, before you begin Step A.

A. In your notebook, make a table like that in Figure 9–3. Fill a beaker about ⅔ full of hot water, as hot as you can get it from the hot-water faucet. Put a thermometer into the water. Start timing when the temperature reaches 65°C, and stop when it reaches 63°C. Record in your notebook the number of seconds it takes for the water to reach 63°C. Empty the beaker.

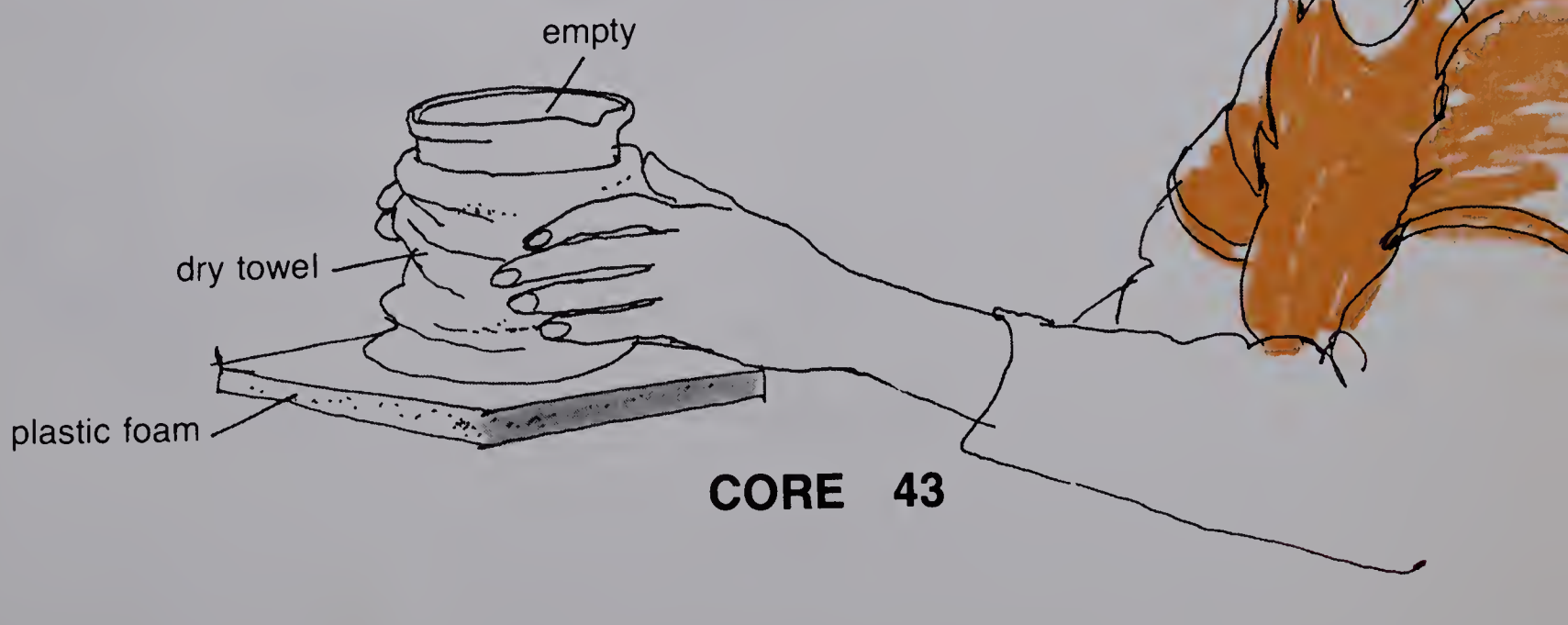


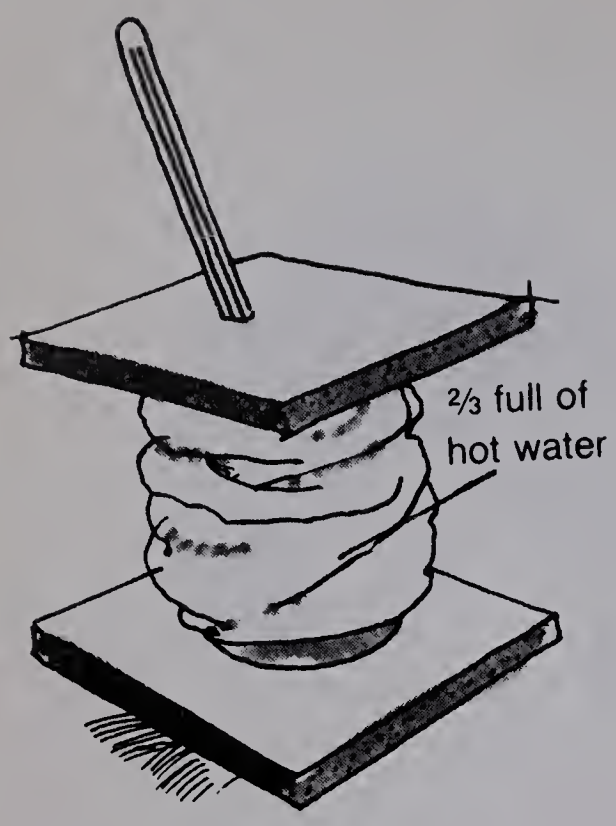
TIME TO COOL

	TIME (IN SEC) TO COOL FROM 65°C TO 63°C
Beaker not wrapped	
Beaker wrapped	

Figure 9–3

B. Stand the beaker on a piece of plastic foam. Wrap the beaker snugly with a dry cloth or paper towel.





C. Fill the beaker about ⅔ full of hot water. Cover with a piece of plastic foam with a hole in the center. Put the thermometer through the hole. Start timing when the temperature drops to 65°C and stop when it reaches 63°C. You may have to pull up the thermometer a few centimetres when you make readings. Record the time in your notebook.

9–4. In which case did heat leave the water faster?

9–5. Does insulation make a difference in heat transfer?

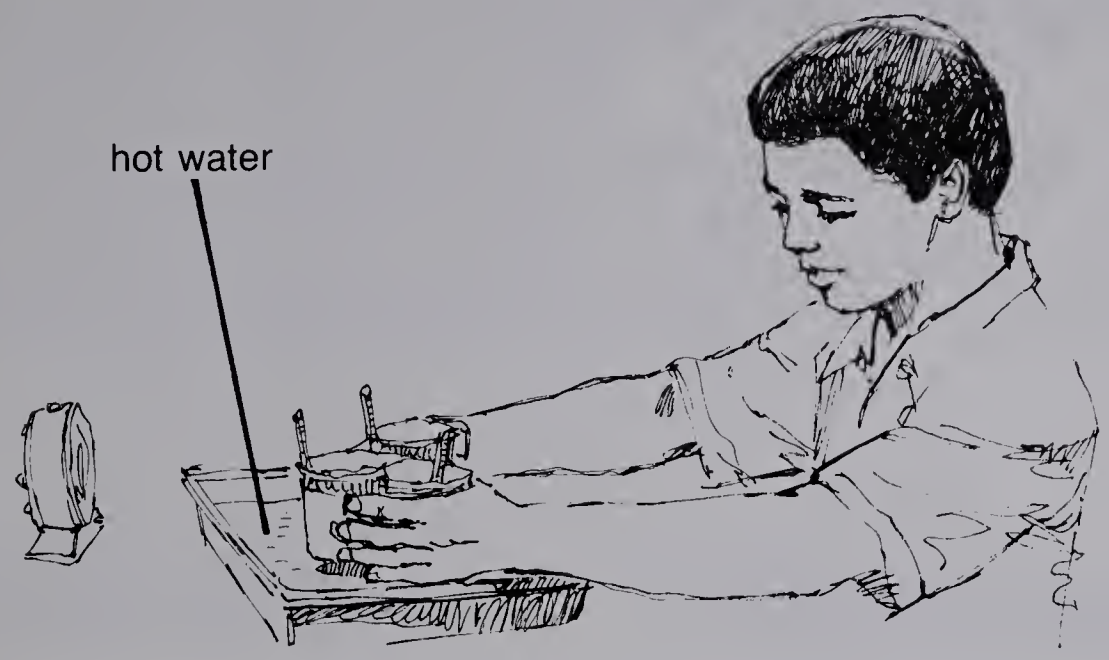
Insulation keeps heat from getting out. Does it also keep it from getting in? You can find out fairly quickly. You will need the following items:

pitcher or other container
beaker, glass, 250-ml
cup, plastic foam, same size as beaker
cup or can, metal, same size as beaker
3 thermometers, 0–110°C
watch or clock with second hand
large pan

A. Fill the beaker, plastic foam cup, and metal cup about ⅔ full of cool water (25°C or below). Put a thermometer in each container. The three temperatures should be the same.



B. Fill the pan with hot water (65°C or above) to about half the height of the beaker. All at one time, set the beaker, metal cup, and plastic foam cup, with their thermometers, into the hot water. At the end of one minute, read the three thermometers.

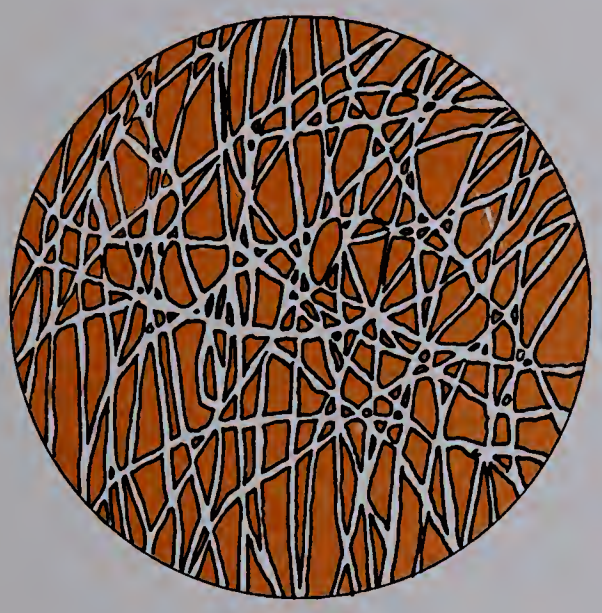


✔ 9–6. Which thermometer showed the greatest change in temperature? The least change?



★ **9–7. Rank glass, metal, and plastic foam in the order of their insulating qualities.**

Plastic foam is full of little air holes. When air can't move around, it makes a good insulator.



Fiberglass has lots of air spaces.



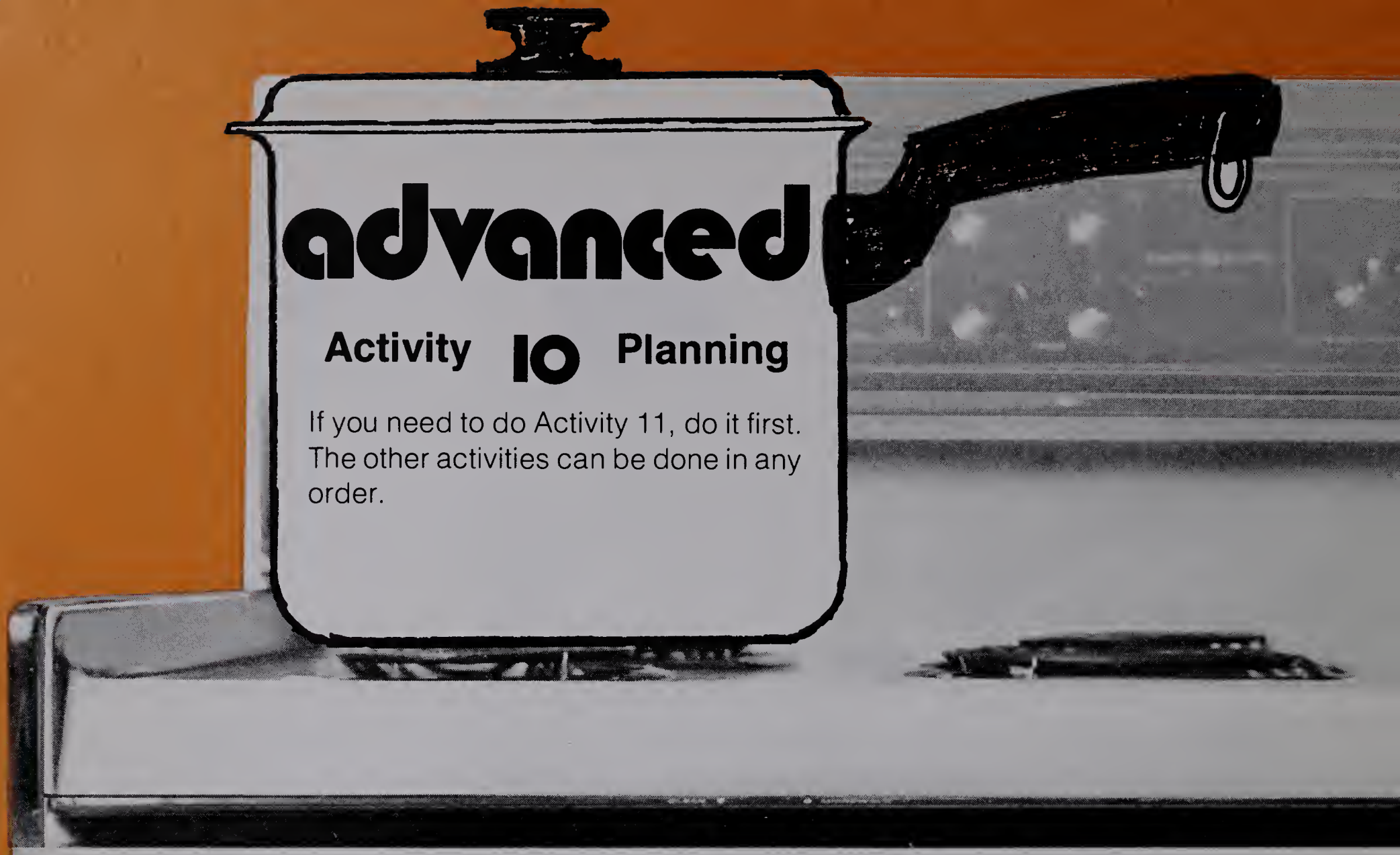
Cork is a light, porous wood.

✔ 9–8. Does ordinary metal have air holes?

In general, any substance that has air spaces is a good insulator. Little air spaces insulate. They can cut energy costs for you.

✔ 9–9. Why does loosely woven cloth keep a person warm?

advanced



Activity 10 Planning

If you need to do Activity 11, do it first. The other activities can be done in any order.

Activity 11 Page 48

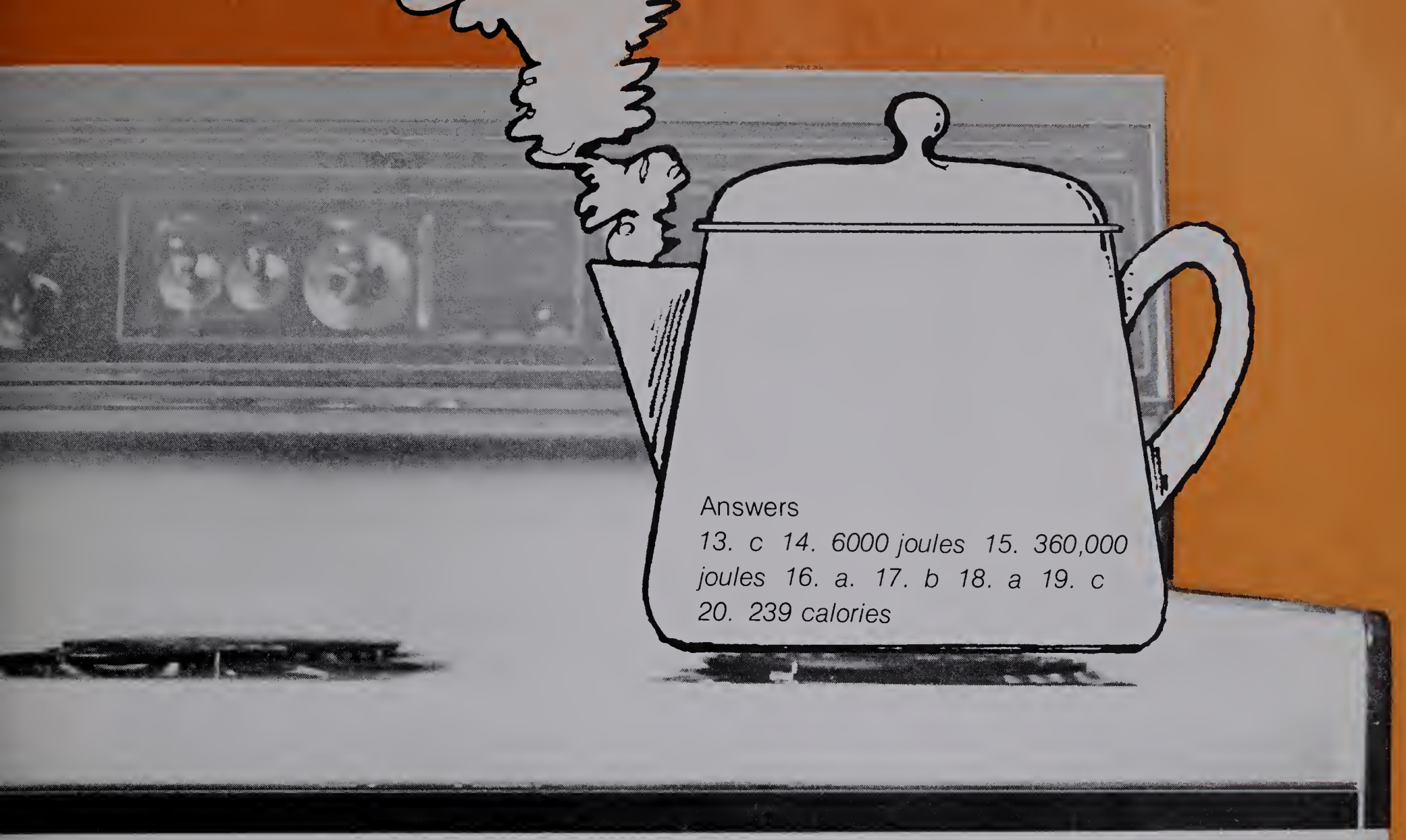
Activity 12 Page 50

Objective 13: Operationally define a joule in terms of power and time.
Sample Question: What is a joule?
a. a watt
b. a kW h
c. 1 watt × 1 second

Objective 14: Calculate the amount of energy in joules consumed by several common appliances.
Sample Question: How many joules of energy does a 100-watt bulb use in one minute?

Objective 15: Calculate the difference in the amount of energy used to heat a quantity of water by electricity and the amount of heat energy given the water.
Sample Question: How many joules of electrical energy are used if it takes six minutes to raise the temperature of 500 g of water from 20°C to the boiling point in a 1000-watt kettle?

Objective 16: Explain the loss in useful energy when converting from electrical to heat energy in a hot-water heater.
Sample Question: In a heater, the input of electrical energy is 180,000 joules, while the output of heat energy is 40,000 calories. A comparison of the input and output shows that
a. heat is lost to the surroundings.
b. heat is gained from the surroundings.
c. the input and output are the same.



Answers
13. c 14. 6000 joules 15. 360,000 joules 16. a. 17. b 18. a 19. c 20. 239 calories

Activity 13 Page 54

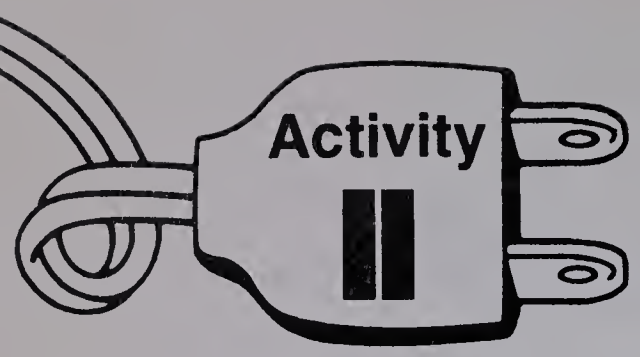
Objective 17: Explain how the kinetic molecular theory is used to describe heat transfer.
Sample Question: The kinetic molecular theory explains conduction of heat in terms of
a. a calorie fluid.
b. molecular collisions.
c. stationary molecules.

Objective 18: In terms of the kinetic molecular theory, describe the motion of air particles as they are heated.
Sample Question: Which of the following mathematical formulas best describes the motion of gas molecules?
a. $KE = \frac{1}{2} mv^2$
b. $E = mc^2$
c. $vt = dm$

Activity 14 Page 58

Objective 19: Describe the experiments of Rumford, Davy, Joule, and Mayer in defining a model for heat.
Sample Question: What did Count Rumford use to show that heat is a form of energy?
a. a paddle wheel that churned water
b. human blood that changed color
c. cannons that gave off heat when bored

Objective 20: Compute the mechanical equivalent of heat.
Sample Question: A rotating frictional device uses 1000 newton metres of mechanical energy in turning. How many calories of heat result if the energy is totally converted?



Measuring Energy

Power is the rate at which energy is used. If you multiply power by the length of time it is used, you get the total energy produced.

11–1. What is the smallest unit of power you have worked with in this minicourse?

11–2. What is the smallest unit of time you have worked with in this minicourse?



Multiplying the smallest units of power and time gives a small unit of energy. It looks like this.

$$1 \text{ watt} \times 1 \text{ second} = 1 \text{ joule}$$

The smallest unit of energy is called a *joule* [JEWL]. A joule is a watt second of energy. It is the amount of energy that an appliance rated at one watt uses in one second.

11–3. How many joules of energy does a 60-watt light bulb use in one second?

11–4. How many joules does it use in a minute?

Get the idea? The number of watts (60) multiplied by the time in seconds (either 1 or 60) gives the energy in joules.

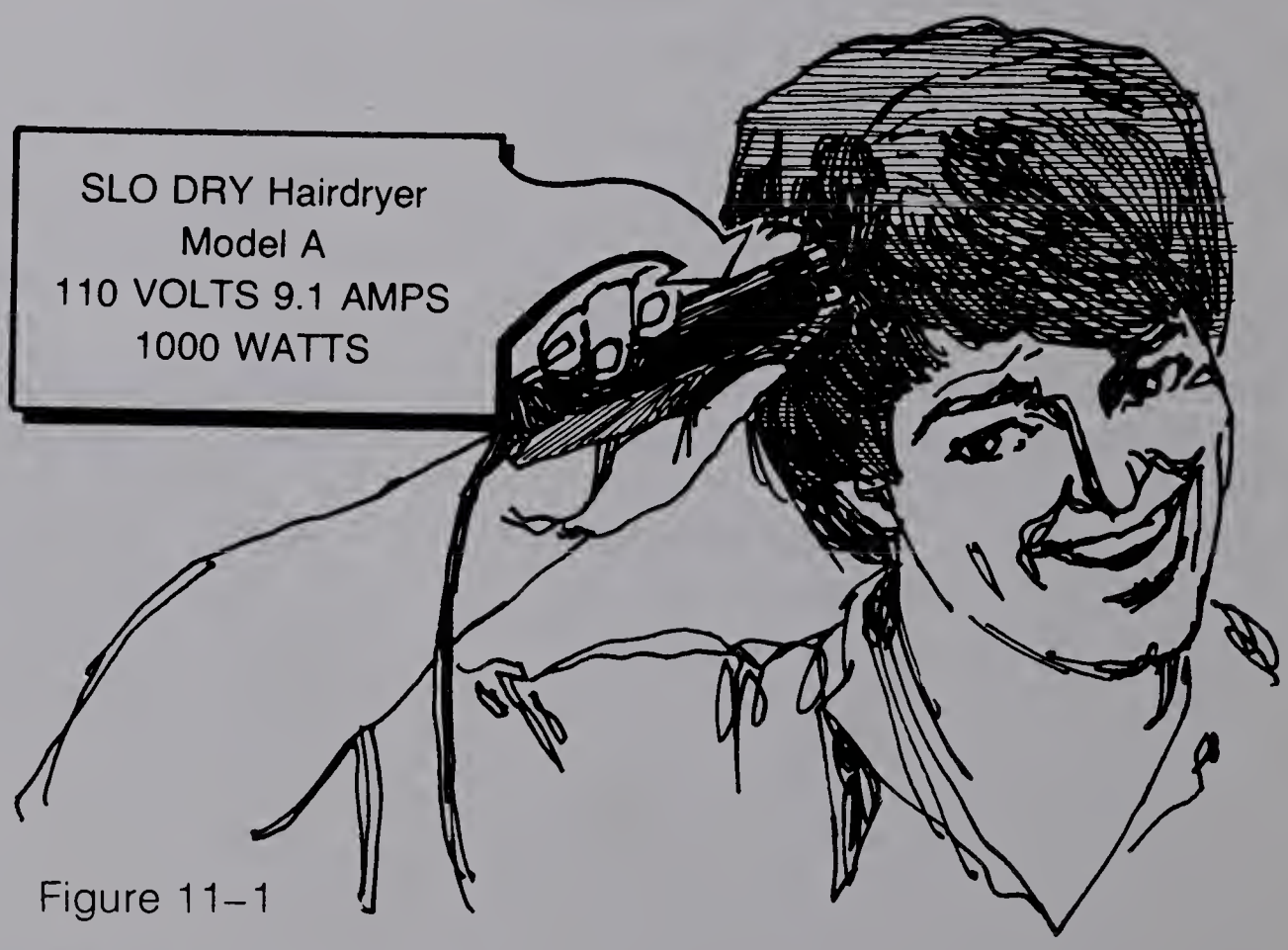


Figure 11–1

✔ 11–5. How many joules of electrical energy are used by the hair dryer in Figure 11–1 in
a. one second?
b. one minute?
c. one hour?

Gets to be a big number fast, doesn't it? The joule is too small a unit to conveniently measure household electricity. It's like measuring the distance to the moon in centimeters, or measuring your age in seconds.

The electric company uses kilowatt hours (kW h) as its unit. A kilowatt hour is the amount of energy used in one hour by a 1000-watt appliance.

1 kilowatt hour = 1000 watts for 3600 seconds

1 kilowatt hour = 1000 joules per second for 3600 seconds

1 kilowatt hour = 3,600,000 joules

★ **11–6. One kilowatt hour equals how many joules of energy?**

There's an easy way to write big numbers like 3,600,000 joules. It's called *scientific notation,* or powers of ten.

✔ 11–7. Write 3,600,000 joules in scientific notation.

Check your answer with your teacher. You'll be using powers of ten as you go on in this activity.

The number of joules in a kilowatt hour should look familiar. It's the same number of joules used by the hair dryer in one hour. In one hour, the 1000-watt dryer used a kilowatt hour (kW h) of electrical energy.

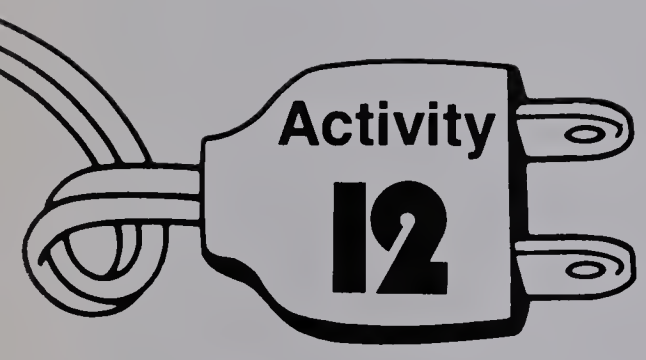
$$\text{kW h} = \frac{\text{watts} \times \text{hours}}{1000}$$

✔ 11–8. How many kW h will a 100-watt bulb use in 24 hours?

✔ 11–9. An electric heating system is rated at 12,000 watts. How many kilowatt hours of energy will be saved, if the thermostat is set so that the system runs 115 hours less per month?

✔ 11–10. In scientific notation, write the number of joules saved in Question 11–9.

★ **11–11. An electric clock is rated at 2 watts. How many joules of energy will it use in a day?**

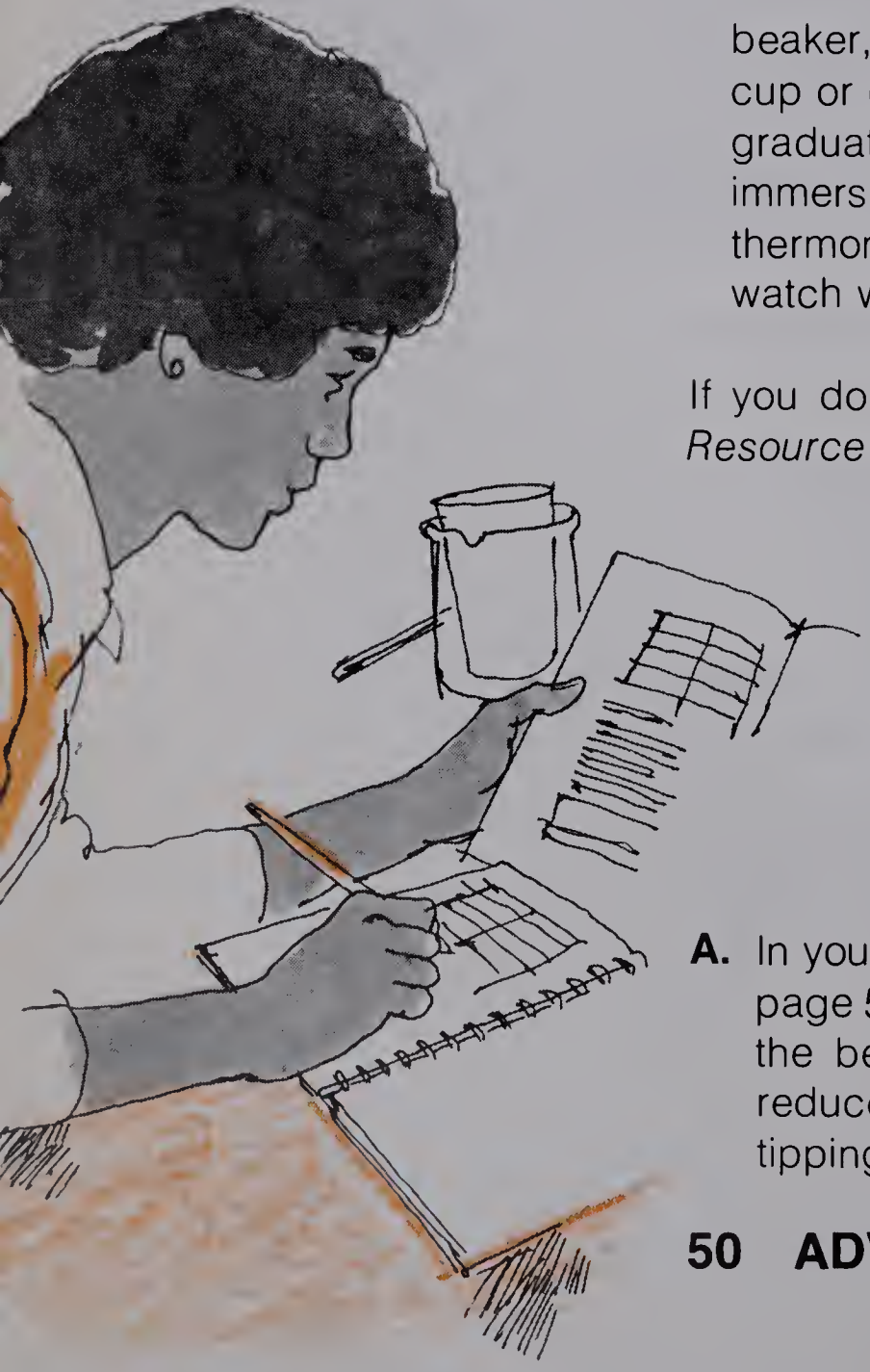


Heat Energy

How much heat energy can you get from an electrical heater? You can find out by using electricity to heat water, and measuring how much electrical energy was used and how much heat was produced. You will need a partner and the following:

beaker, 250-ml
cup or can holder, plastic foam
graduated cylinder, 100-ml
immersion heater, 75–150 watt, 110-volt
thermometer, 0–110°C
watch with second hand

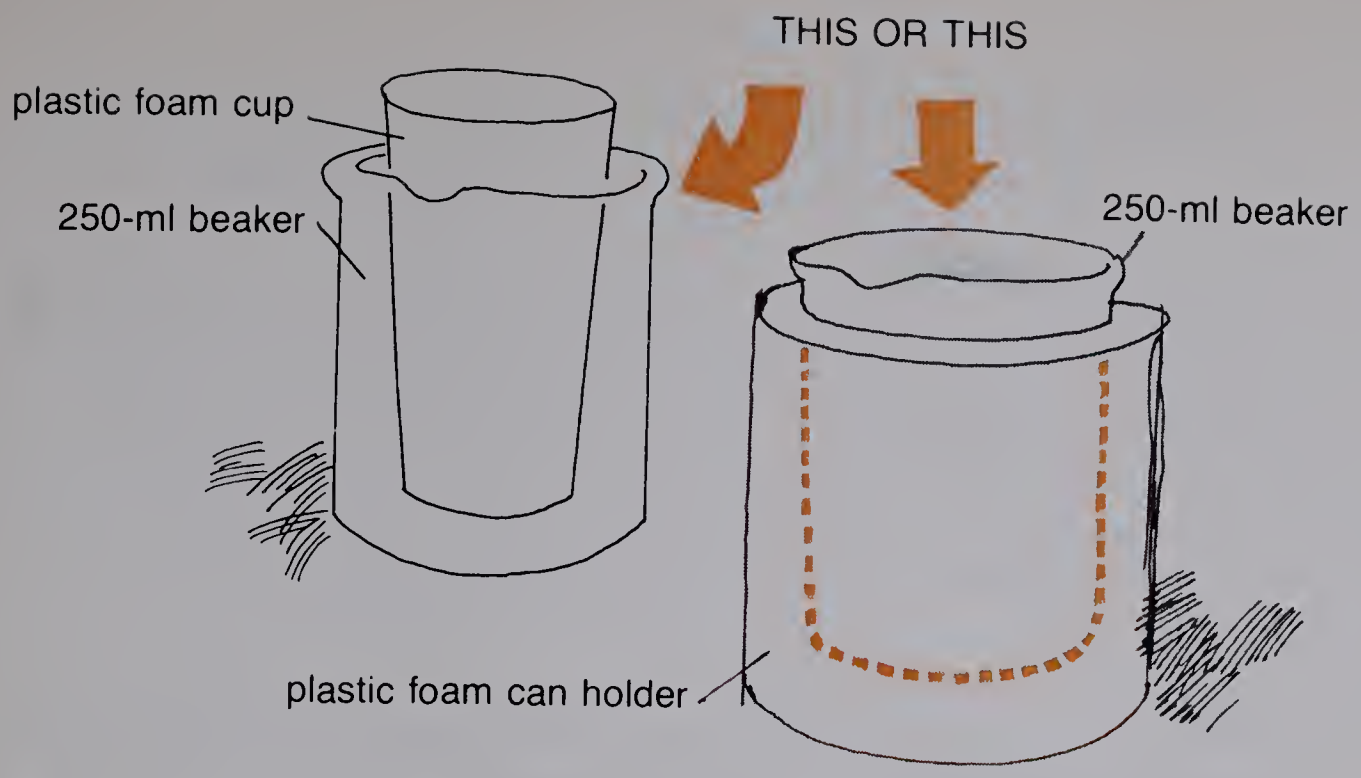
If you don't know how to use the graduated cylinder, refer to *Resource Unit 5.*



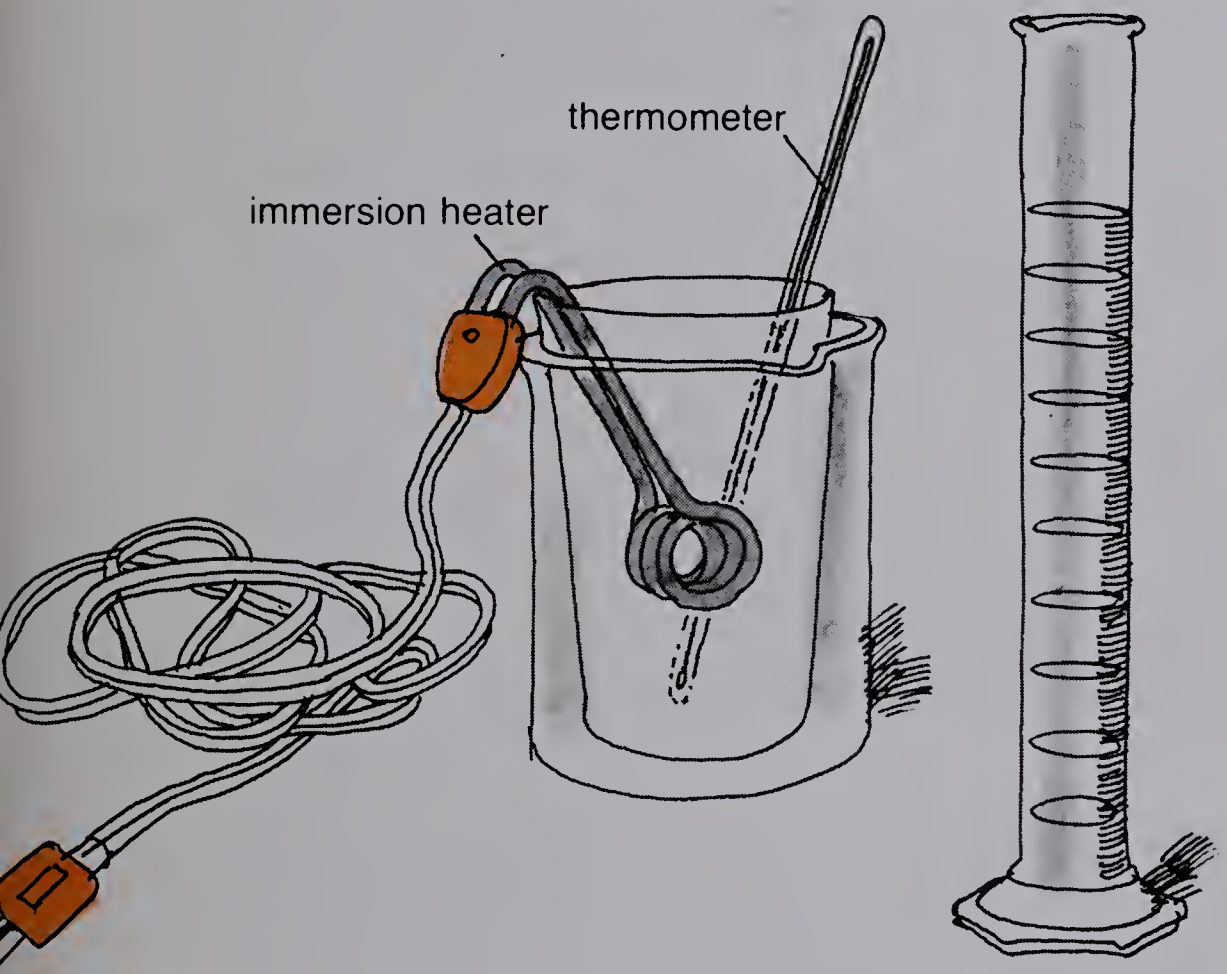
CAUTION

Don't plug in the immersion heater until the instructions tell you to.

A. In your notebook make a table like the one in Figure 12–1 on page 52. Set the plastic foam cup inside the 250-ml beaker, or the beaker inside a plastic foam can holder. The cup will reduce heat loss, and the beaker will keep the cup from tipping over.



B. Add 150 ml of *cold* water to the cup or beaker. Record the volume of water in your table. Now stand the immersion heater and the thermometer in the cup or beaker. Be sure the heating coil is completely covered with water. Record the temperature of the water in your table.





C. Plug in the heater and immediately record the time. One partner should watch the time and unplug the heater in exactly 2 minutes (120 seconds). The other partner should stir the water and read the temperature. In 2 minutes pull the plug. Read and record under "final temperature" the highest temperature of the water. Also record the final time and the wattage rating of the heater.

COMPARISON OF ELECTRICAL ENERGY AND HEAT ENERGY

ELECTRICAL ENERGY	HEAT ENERGY
Voltage = (?) volts	(?) °C end
Current = (?) amperes	(?) °C start
Power = (?) watts	(?) °C change
Elapsed time = (?) seconds	Volume of water = (?) ml

Figure 12–1

12–1. Suppose only voltage and amperage are given on the heater. How would you find the wattage?

Not all the electrical energy was used to heat the water. The thermometer, the containers, and the heater itself were also heated. And, even though you used plastic foam containers, some of the heat leaked out. This loss of heat to the surroundings became greater as the water temperature increased. (See Figure 12–2.)

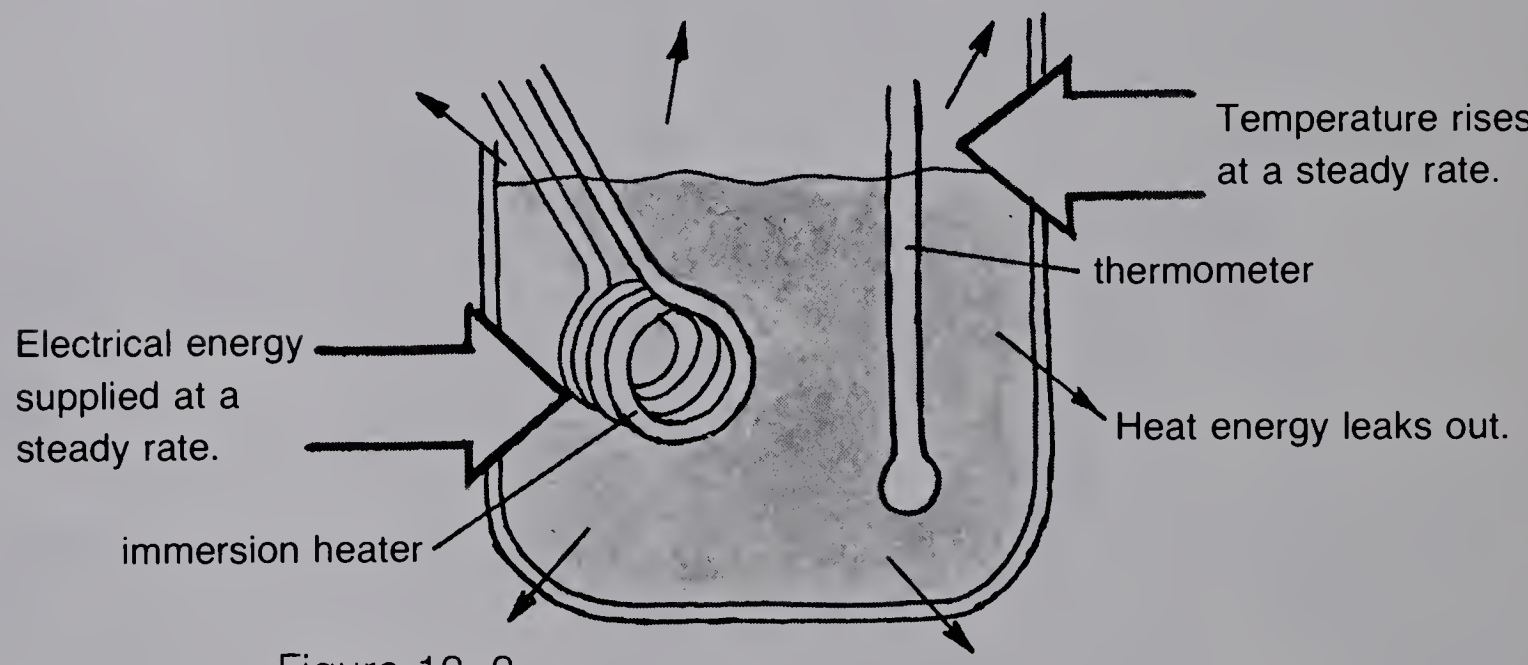


Figure 12–2

12–2. In addition to the heat losses to thermometer and containers, and through the containers, what other way is heat lost?

Now, compare the electrical energy used and the heat energy produced. How much electrical energy was used? To answer this question, you can use any of these formulas:

electrical energy = joules per second × seconds
(in joules) = watts × seconds
= volts × amperes × seconds

✔ 12–3. From the data in your table, calculate the number of joules of electrical energy used in your investigation.

Heat energy is usually measured in calories. One calorie is the amount of energy needed to raise the temperature of one gram of water by one degree Celsius. Using the calorie, it's easy to calculate the amount of heat energy absorbed by the water up to its boiling point at 100°C. So, for water—

calories = grams of water × degrees Celsius

To calculate the heat energy absorbed during your investigation, you need to know how many grams of water you heated and the temperature change of the water. You can get this information from your table, if you know that one millilitre of water weighs one gram.

✔ 12–4. Collect the data called for in Figure 12–3 from your earlier work. List it in your notebook.

DATA FOR CALCULATION OF HEAT ENERGY

Volume of water heated =	(?)	ml
Weight of water heated =	(?)	g
Temperature at beginning =	(?)	°C
Temperature after 2 minutes =	(?)	°C
Rise in temperature =	(?)	°C

Figure 12–3

✔ 12–5. How many calories of heat were absorbed according to your data?

Now you have two values for the energy exchanged during your investigation. One is the electrical energy in joules from Question 12–3. The other is the calories of heat energy from Question 12–5.

Did the water absorb all the energy the immersion heater provided? To answer this, you need to change the calories into joules. A calorie is about the same amount of energy as 4.184 joules. In this case, it's close enough to use 1 calorie = 4 joules. It certainly makes the calculations easier!

✔ 12–6. Use 1 calorie = 4 joules to change the calories in Question 12–5 into joules.

✔ 12–7. How did the number of joules of heat energy absorbed compare with the number of joules of electrical energy used?

As a summary, try another problem of electrical-to-heat energy change.

★ **12–8. A 100-watt heater is used for two minutes to heat 100 g of water. The temperature of the water rises 25°C. What is the difference in joules between the electrical energy used and the heat energy absorbed?**

★ **12–9. Explain any difference between the two figures you found in Question 12–8.**



Hot Air

We live in an ocean of air. If the air around our bodies gets too cold, it must be heated to keep us comfortable. Heat, or *thermal energy,* from a stove, radiator, heating coil, or furnace, must be transferred to the air.

How is thermal energy transferred to the air? A series of investigations can show how it happens. You will need about 30 minutes and the following materials:

Bunsen burner	test tube, 20 × 75 mm
glass rod, 10–15 cm	safety goggles
metal rod, 10–15 cm	

If you have not used a Bunsen burner, do *Resource Unit 17* before you begin Step A.

A. Hold one end of a metal and one end of a glass rod in the flame of a Bunsen burner. Hold the rods until one of them becomes uncomfortably warm. Then lay them in a safe place to cool.

CAUTION

Be sure the hot rods are not touched by you or someone else.



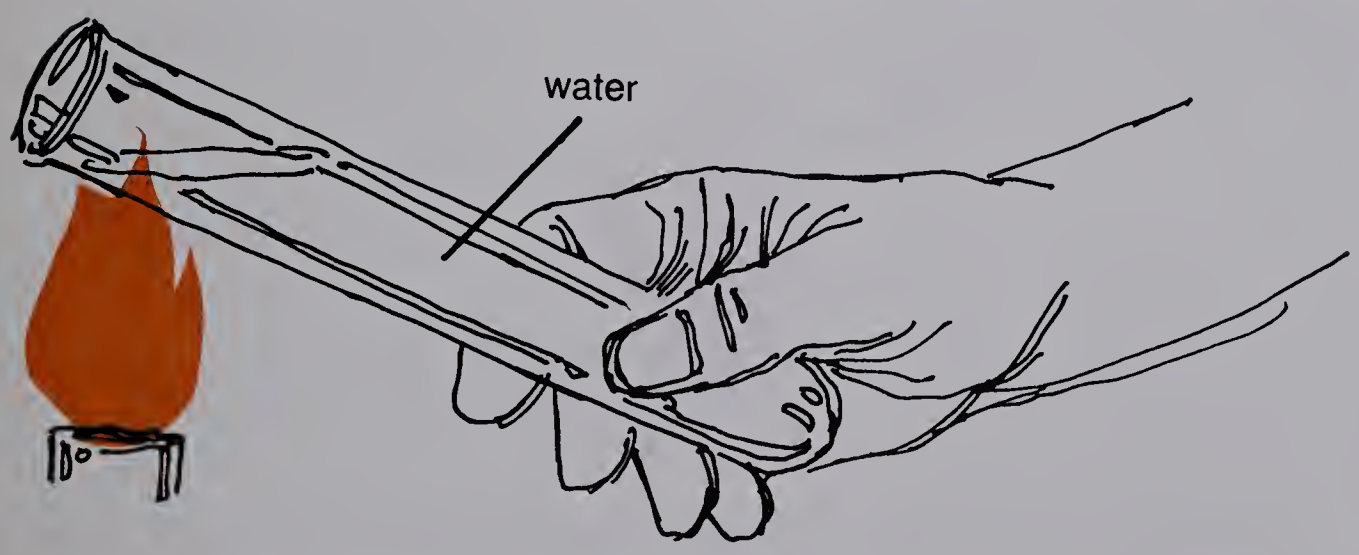
13–1. Which rod got hot first?

Somehow heat energy passed from one end of the rod to the other. Heat is transferred through a solid by *conduction.* Conduction is a process in which thermal energy is passed from one particle to a neighboring particle. There is no mass motion of the substance, only particle vibrations.

13–2. What evidence do you have that some particles pass this vibrational energy better than others?

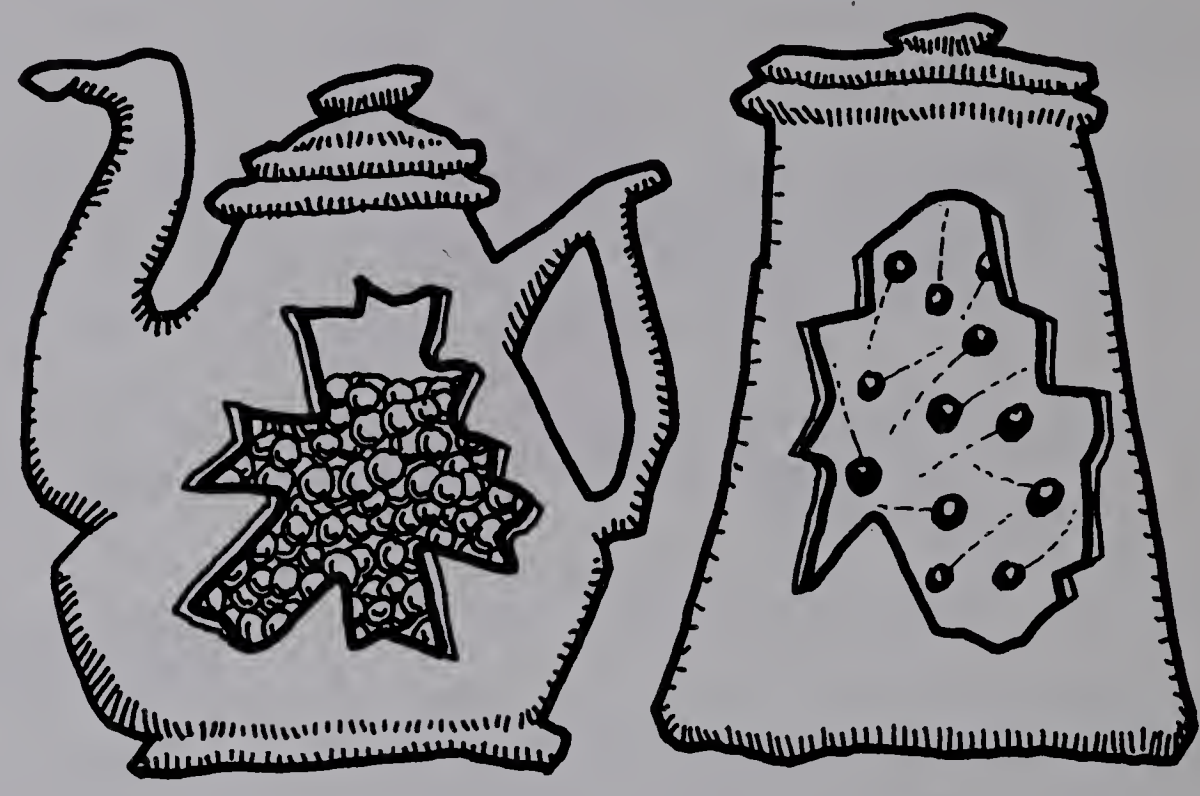
In liquids, particles have more freedom for motion than in solids. Would you expect conduction of thermal energy in liquids to be better than in solids? You can find out.

B. Fill a test tube with water within 3 cm of its top. Hold the tube at the bottom in an inclined position, so that the flame of the burner hits the tube just below the water level. Heat until the water at the top of the tube is boiling.



13–3. Is water a good or a poor conductor of heat?

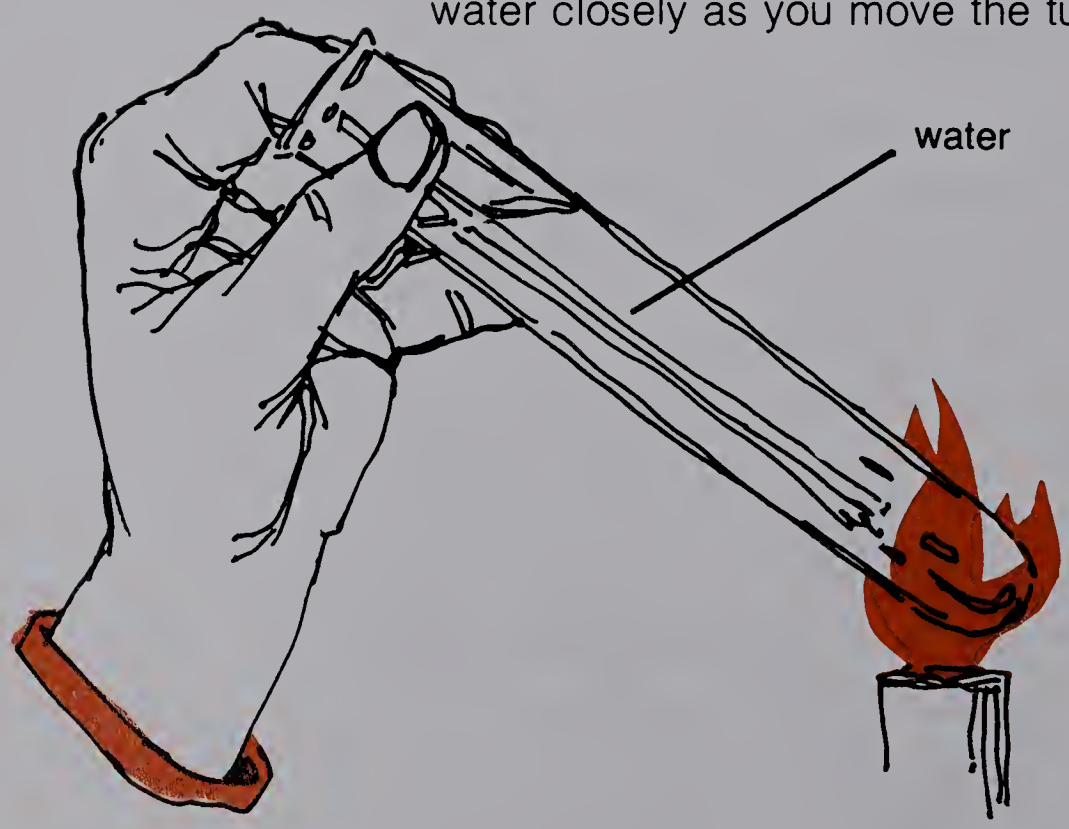
In a liquid, thermal energy is not transferred very well by conduction. Actually, it is transferred by liquids in a different way (and slower) than by solids. In a gas, the particles are farther apart than in a liquid or solid, and there is even less conduction of heat.



LIQUID GAS

✔ 13–4. Would you predict air to be a good or a poor conductor of heat? Explain your answer on the basis of particle collisions.

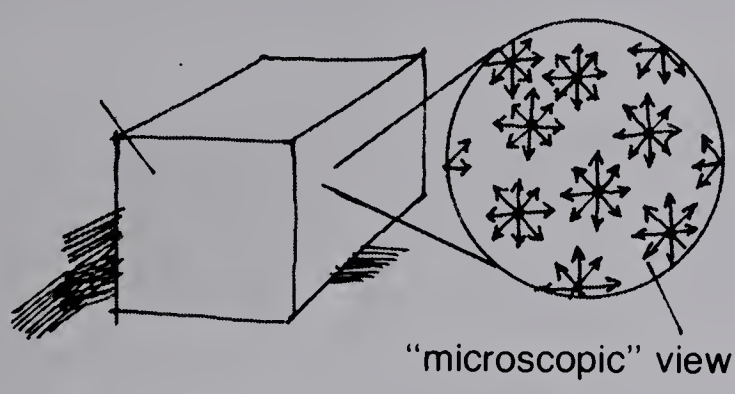
C. Empty the test tube and refill it with cold water to within 3 cm of its top. This time hold the test tube near the open end in an inclined position, with the flame hitting the bottom of the tube. Move the tube slowly back and forth in the flame. Observe the water closely as you move the tube.



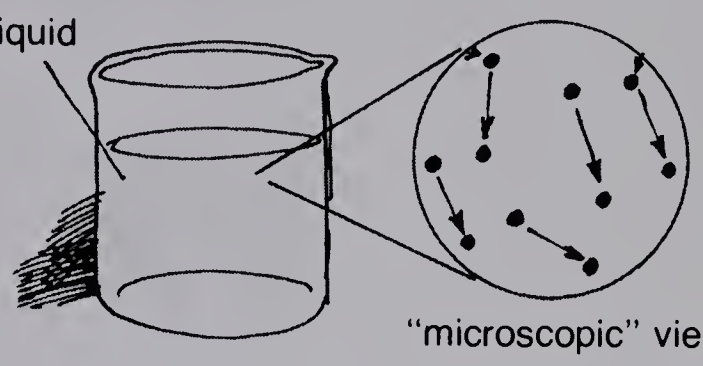
✔ 13–5. Describe your observation of the water and of the transfer of heat.

You know that little heat was transferred by conduction. But you may have seen currents in the water. Heat was transferred by these moving currents of water. The transfer of thermal energy from one place to another by the motion of a mass of heated liquid or gas is called *convection.*

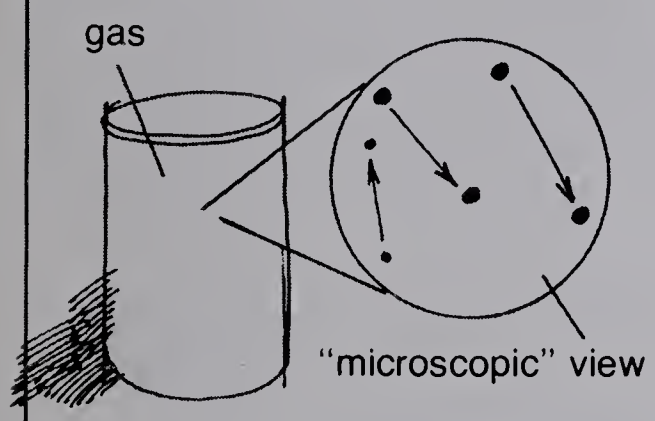
What is the heat or thermal energy that is transferred by conduction or convection? Scientists theorize that it is simply a form of the mechanical or motion, energy of the particles of a substance. This is called the *kinetic molecular theory* and can be summarized as follows:



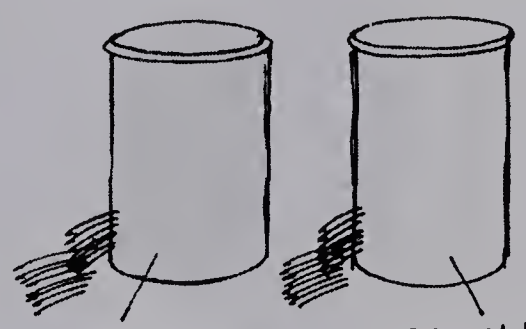
1. In a solid, motion energy consists of small vibrations because the particles cannot move freely in any direction.



2. In liquids, there is freedom of motion of the particles, but they are still close together.



3. In a gas, particles are free to move in all directions.



4. The average energy of the particles is related to the temperature of the substance. The higher the temperature, the greater the average energy of motion.

$$K.E. = \frac{1}{2} mv^2$$

5. The energy of motion of the particles is dependent on their velocity, or how fast they move. The kinetic energy of a moving particle can be written K.E. $= \frac{1}{2} mv^2$, where m is the mass of the particle and v is its velocity.

★ **13–6. Tell why the average velocity of air particles at a high temperature is greater than that of air particles at a low temperature.**

In the process of heating a room with a stove or radiator, the cold air molecules traveling at a low velocity collide with the hot surface of the radiator or stove. Because the radiator is at a higher temperature than the air, the air molecules leave the stove or radiator with more energy, and a higher velocity.

★ **13–7. By what process, convection or conduction, is heat energy transferred from a hot radiator to air molecules that collide with it?**

Hot air molecules moving at a higher velocity occupy more space than cold air molecules. This means that hot air is less dense than cold air, and so it rises, like the hot water did in the test tube. As the hot air rises, cold air sinks and comes in contact with the hot surface. This cold air is heated. Thus, heat is transferred to the air, and all the air in the room is heated.

✓ 13–8. By which of the two processes, convection or conduction, is heat energy distributed throughout a room?

Heat energy is transferred by conduction from a hot stove or radiator to air molecules. The heat is distributed throughout the room by convection. When hot air molecules collide with cool walls and windows, they give these surfaces some of their energy by conduction.



Rumford, Davy, Joule, and Mayer

The title of this activity isn't the name of a law firm, even though it may sound like one. The title is made up of the names of four scientists, each of whom made a contribution to our understanding of heat and helped give us a new theory.

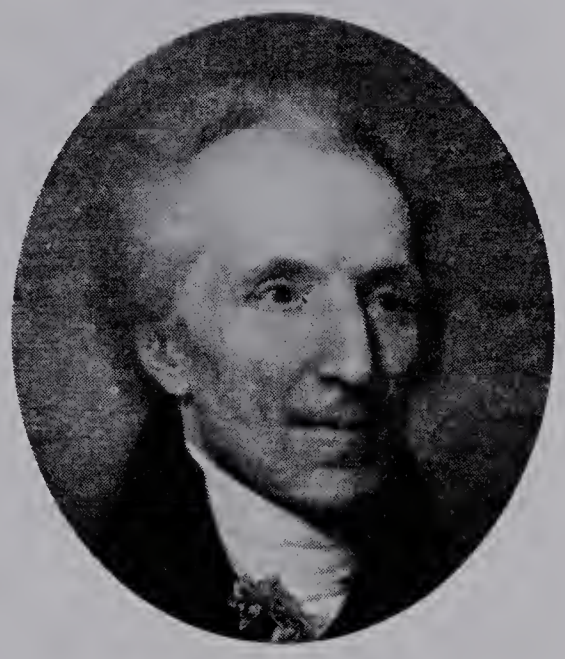
It's hard to describe something that doesn't have physical shape. For instance, you've seen rocks and can tell someone what they look like. But it's hard to describe a force, because you can't see a force. You can only see its effect on something.

Early scientists had a similar problem when they tried to describe heat. They could see its effect on things, but they couldn't see heat. In describing heat, they thought of it as a substance that could flow in or out of an object. They called this heat substance *caloric* [ka-LOR-ik].

The scientists' theory of caloric explained most of the behavior of heat. And many scientists in the mid-1700s were satisfied with the theory. But there were some skeptics. We will look at these doubters in pairs.

The Birth of a New Idea

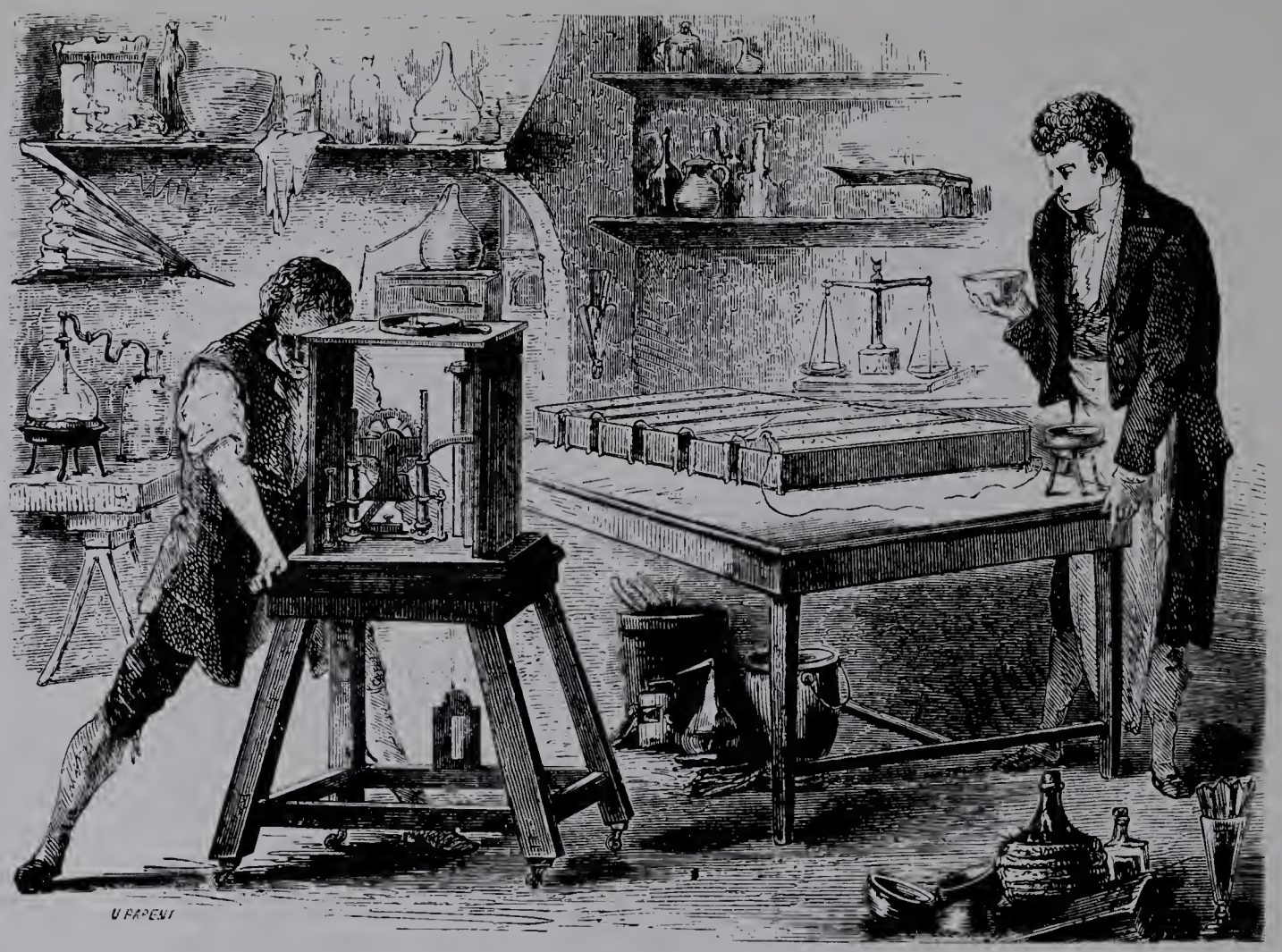
One day in 1798, Count Rumford of Bavaria, born Benjamin Thompson in Woburn, Massachusetts, was supervising the boring of brass cannon in the arsenal in Munich. He was impressed by the large amount of heat given off in the operation. In fact, the supply of heat seemed limitless; it continued as long as the boring tool turned in the metal. Rumford concluded that heat wasn't a substance. There was no such thing as caloric. Instead, he reasoned that heat was due to friction—the mechanical work that was done in boring the cannon.



Portrait of Count Rumford painted by Rembrandt Peale.

A year later, in 1799, a 21-year-old English scholar performed some experiments that further refuted the caloric theory. His name was Humphry Davy. He later achieved fame as a great chemist by discovering the chemical elements barium, boron, calcium, potassium, sodium, and strontium.

Davy set up an apparatus by which he could rub substances together in a vacuum. Using his apparatus he melted ice and wax while their temperatures were below freezing. If the caloric theory were correct, caloric would have been added to the ice and wax in order for them to melt. But where could the caloric come from? Davy concluded that heat must have come from the rubbing action.



Sir Humphry Davy's laboratory

✔ 14–1. How were the experiments of Rumford and Davy similar? How were they different?

Both Davy and Rumford proposed that heat was a form of motion. Old ideas die slowly, so the caloric theory remained popular for almost fifty years. Joule and Mayer brought on the final death of caloric.

The Death of an Old Idea

James Prescott Joule [JEWL] and J. Robert Mayer were entirely different types of individuals. Joule was a prominent physicist; Mayer an obscure physician. Joule had a superb scientific education; Mayer lacked this advantage. Joule had the ability and the facilities to do experimental work; Mayer had neither. But working independently, each came up with the same assertion—that heat could be converted into mechanical energy, and mechanical energy could be converted into heat.

Joule performed many different investigations in which he converted various kinds of energy into heat. He demonstrated that mechanical energy could be changed into heat in several ways. In one classic experiment, he churned water with paddle wheels turned by falling weights. He made careful measurements of the

amount of work done by the falling weights and the rise in temperature of the water, thus relating mechanical work and heat. After his many experiments, Joule concluded that a one-pound weight falling 772 feet made the temperature of one pound of water rise one degree Fahrenheit. (Notice the English units.)



James Prescott Joule

Without the ability or facilities to experiment, Mayer used a different approach. He applied reasoning to the problem. Mayer, selecting with great acuity from existing experimental evidence, concluded that the warming of a given weight of water one degree Celsius corresponded to a fall of 365 metres by an equal weight of water. (Note the metric units.) Under different circumstances, Joule could have been Mayer, and Mayer could have been Joule.

✔ 14–2. By different methods, the Englishman Joule and the German Mayer came to the same conclusion about heat. What was their conclusion?

Modern computations show that Joule's number should be 778 instead of 772, and Mayer's number 427 instead of 365. Buf the idea was valid. Other scientists who followed added their support to the idea of a mechanical equivalent of heat. The caloric theory was dead and buried for all time.

Mechanical Equivalent of Heat

Mechanical work is measured in newton metres in the metric system. A newton metre is the amount of mechanical work done when one newton of force is exerted over the length of one metre. To get newton metres of work, you multiply the force in newtons by the distance in metres.

newtons × metres = newton metres

✓ 14–3. Suppose an object weighing one newton falls one metre. How much work has been done by the weight?

One newton metre of work is equivalent to one joule of mechanical energy. So a one newton weight falling one metre develops one joule of mechanical energy to turn paddles and churn water.

✓ 14–4. If a one newton weight falls 4.184 metres, how much work has been done by the weight?

★ **14–5. If an object weighing 4.184 newtons falls one metre, how much work has been done by the object?**

✓ 14–6. If an object weighing 8.368 newtons falls 50 cm (one-half a metre), how much work has been done by the object?

Your answers for the last three questions should all be the same (4.184 newton metres or joules). This is the mechanical equivalent of heat that Joule and Mayer defined—that many joules of energy (4.184 joules) will raise the temperature of one gram of water one degree Celsius. That's one calorie of heat energy.

★ **14–7. Complete this table of energy equivalents.**

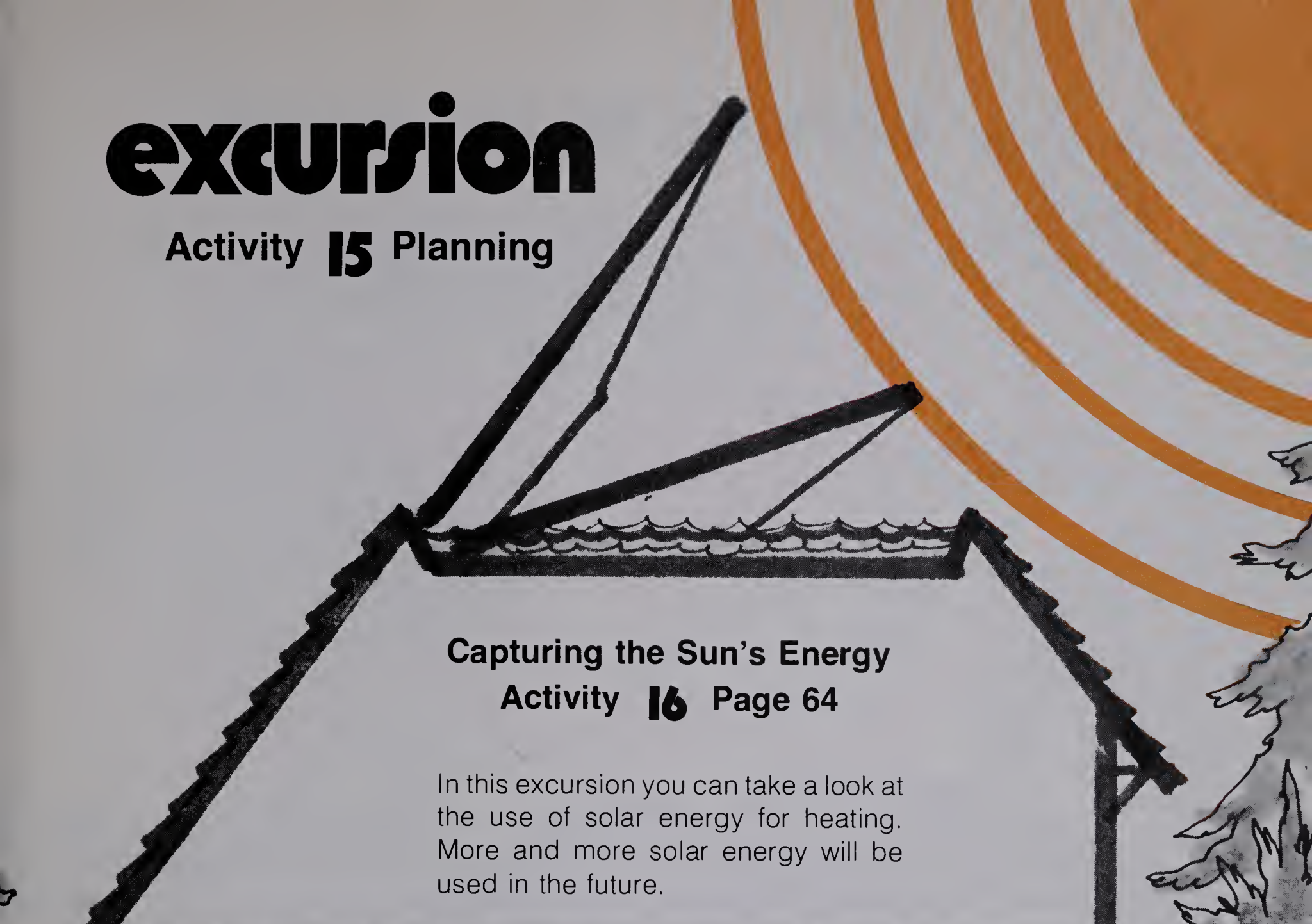
1 calorie = __(?)__ joules = __(?)__ newton metres

Suppose you had a container that held 1000 g of water. That's 1000 ml, or 1 litre of water. It's a little over a quart. The water is churned by paddles turned by falling weights. Assume all of the mechanical work goes into heating the water.

✓ 14–8. How many newton metres, or joules, of energy must be transformed by falling weights to raise the temperature of the 1000 g of water 10°C?

excursion

Activity 15 Planning



Capturing the Sun's Energy
Activity 16 Page 64

In this excursion you can take a look at the use of solar energy for heating. More and more solar energy will be used in the future.

A Penny Saved Is a Penny Earned
Activity 17 Page 69

Everyone should be trying to keep the cost of energy down. Here are some hints on saving money for hot water, refrigeration, and cooking.



Retaining Energy
Activity 18 Page 75

Here's your chance to test an important scientific idea on your own. It's called the "greenhouse effect," and it has important practical applications.

Activity 16

Capturing the Sun's Energy

All the energy on Earth, except atomic energy has come from the sun. But we make use of only a part of the energy the sun sends. Much energy is reflected back into space.



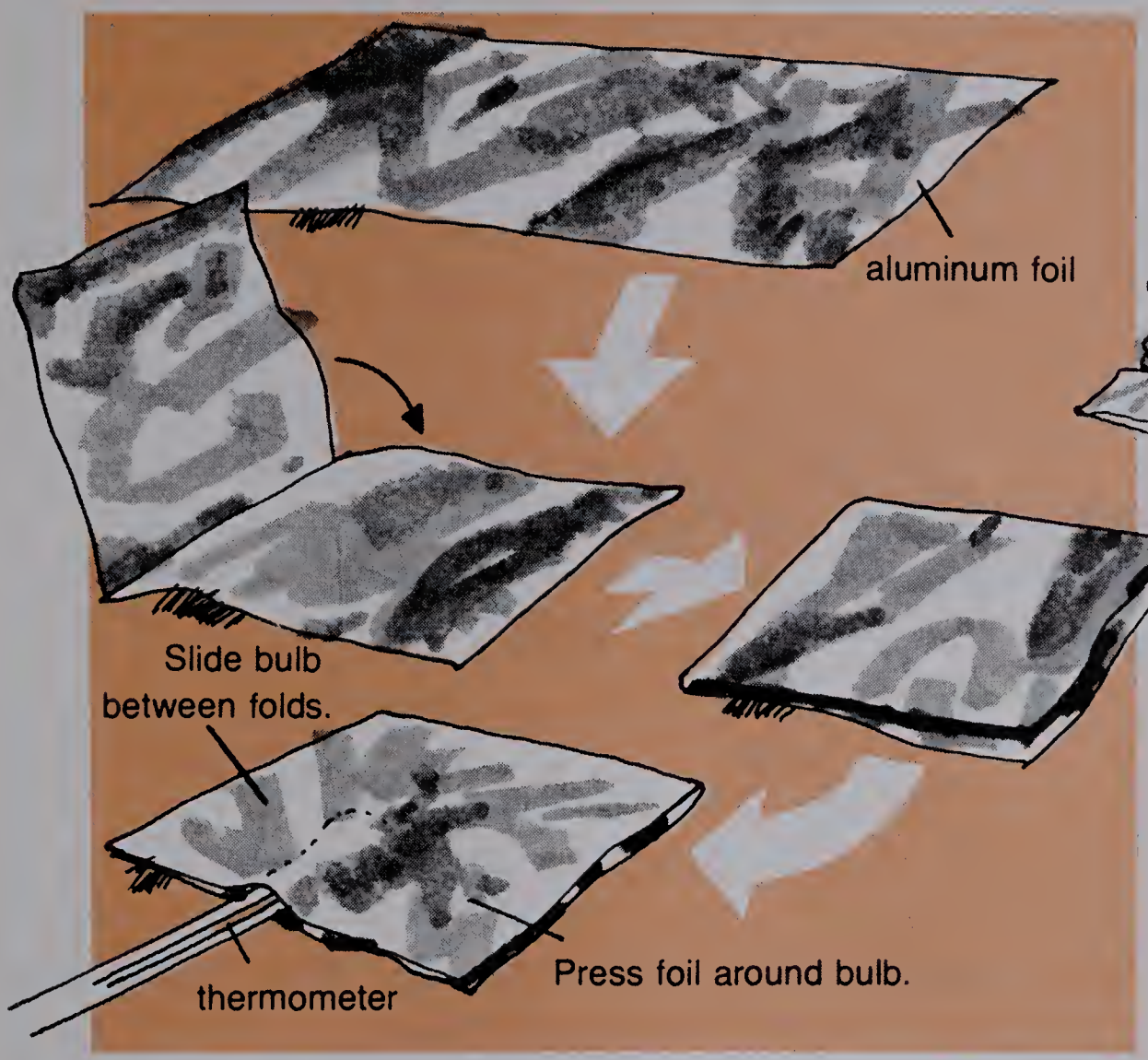
As energy from coal, oil, and natural gas becomes scarcer and more expensive, the idea of using solar energy becomes more attractive. Huge amounts of energy reach Earth every day from the sun. If the solar energy hitting the United States could be captured and used, it would certainly help to make our remaining reserves of coal, oil, and natural gas last longer.

You know that much of the energy used in a home goes for heating devices. It costs to heat your home, heat water, dry clothes, and cook food. If energy from the sun would do some of this heating, you could save money.

But can the sun's energy be captured? The following investigation will give you some idea. You will need about 30 minutes and the following items:

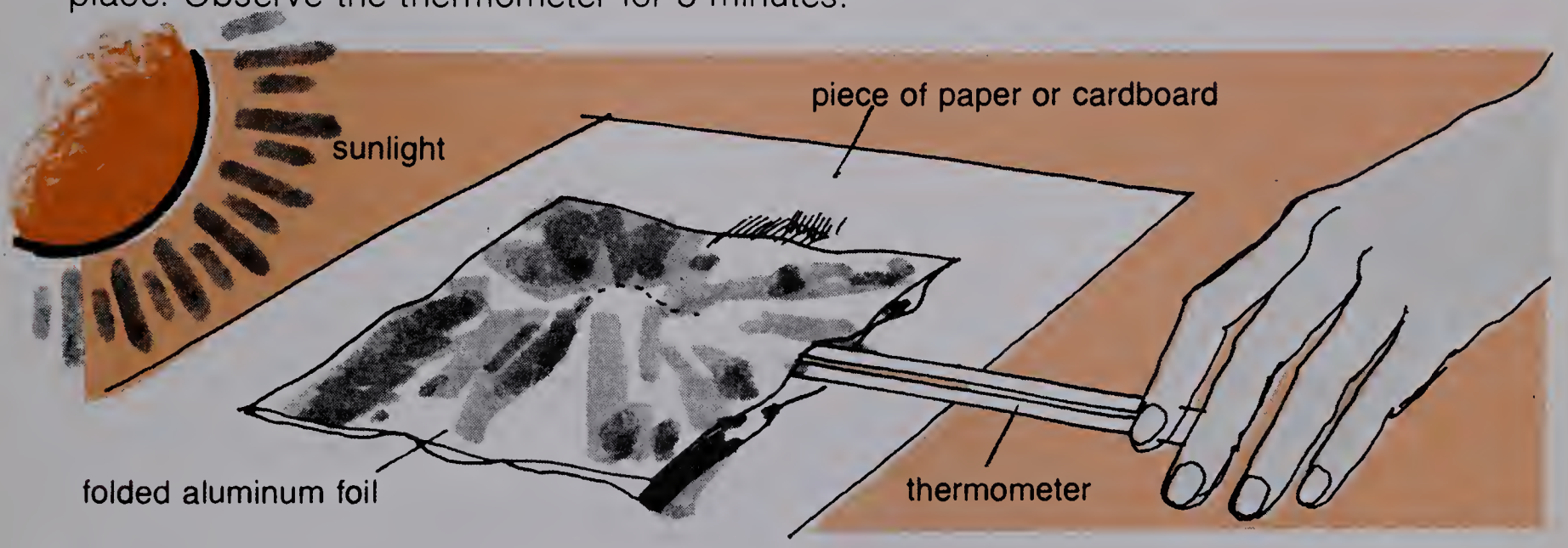
thermometer, 0–110°C
foil, aluminum, 10 cm × 3 cm
paper or cardboard, 10 cm × 12 cm
candle
match
tweezers

A. Fold the piece of aluminum foil into a 5 cm × 3 cm rectangle. Slide the bulb of the thermometer between the folds and press the foil tightly around the bulb.





B. Set the thermometer and foil on a piece of paper or cardboard in *direct sunlight*—on a windowsill or outside in a protected place. Observe the thermometer for 5 minutes.



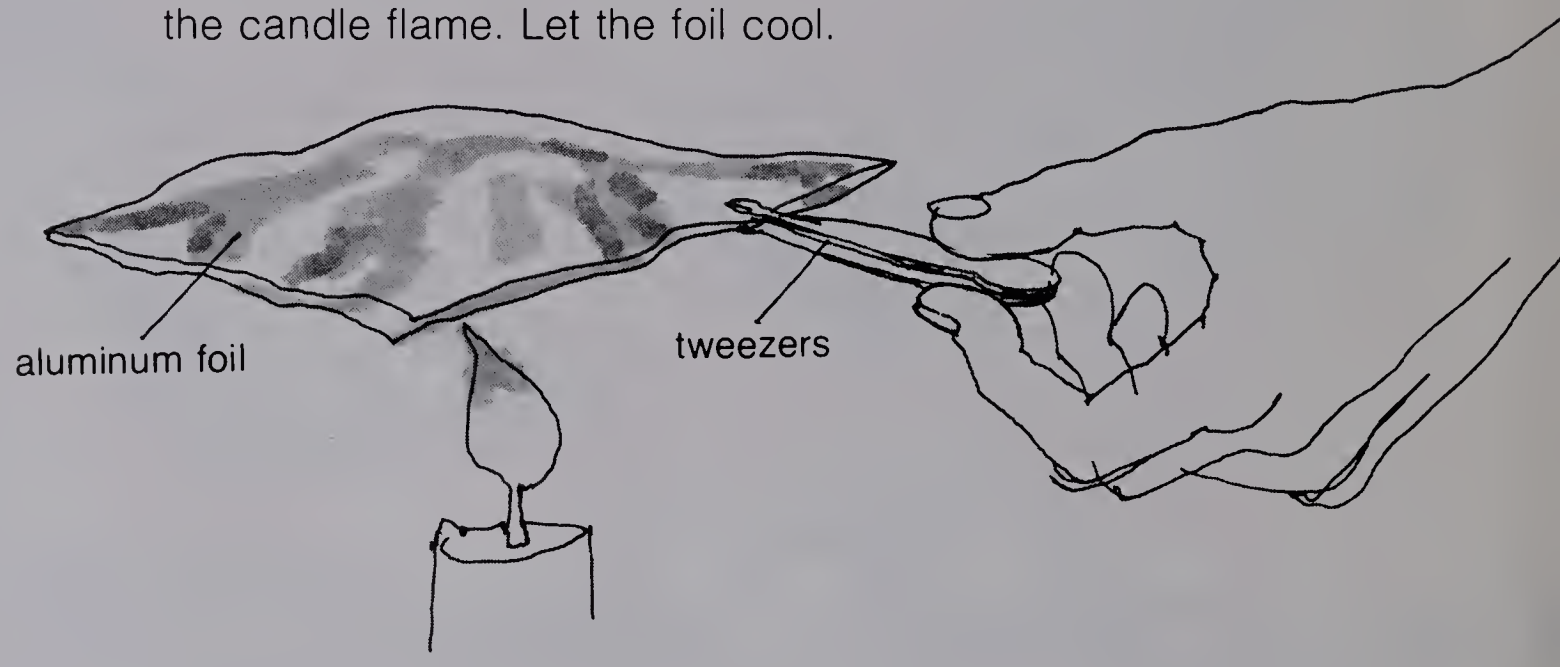
16–1. Describe any change in the thermometer.

★ **16–2. What happens to most of the solar energy that strikes aluminum foil?**

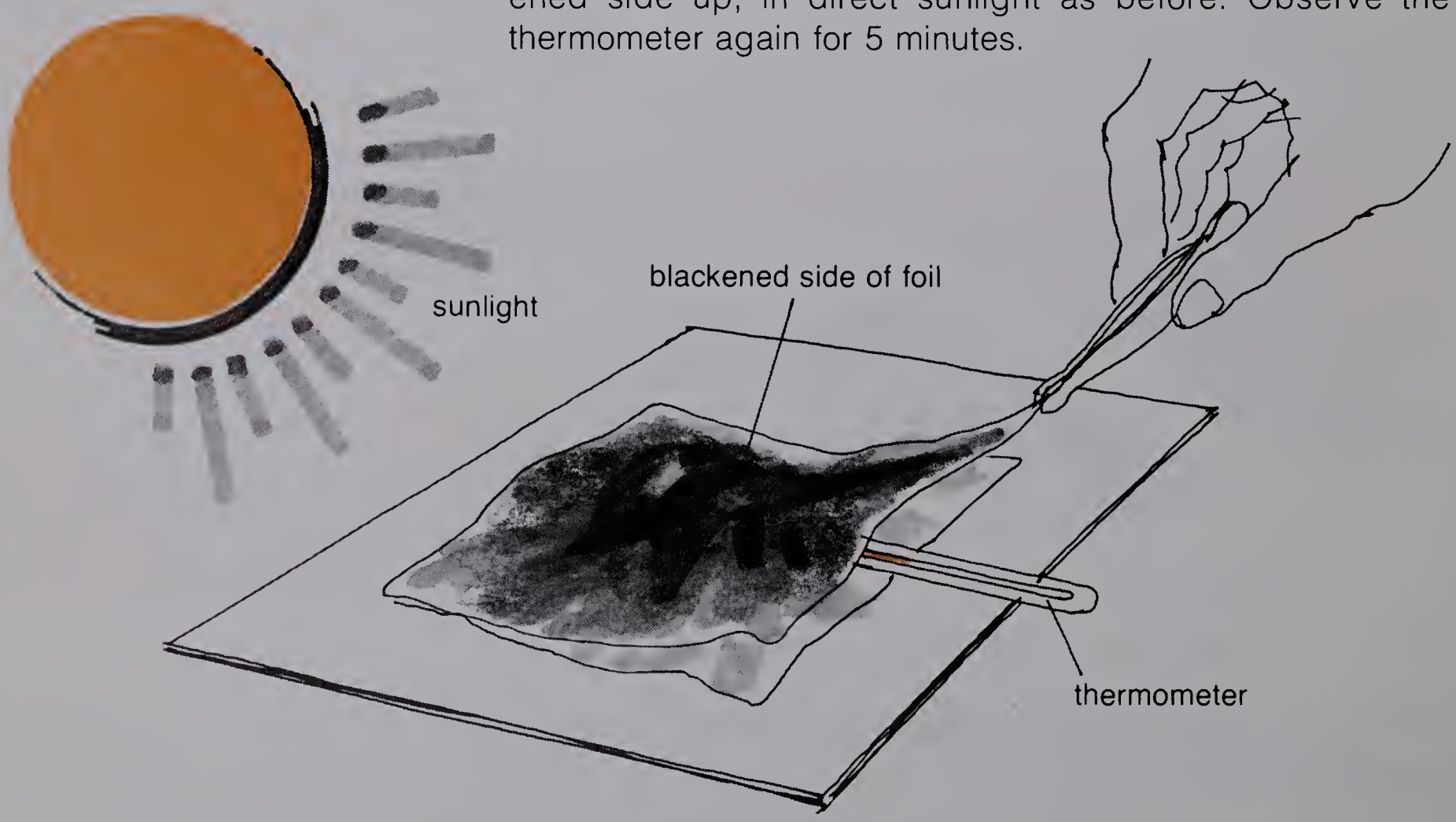
Sunlight that isn't captured can't help you very much. Most of the light that strikes the aluminum foil is reflected from the surface. If the foil were a better absorber, more light energy could be captured.

✔ 16–3. What can you do to the foil so that it will capture more light energy?

C. *Carefully* slide the foil off the thermometer bulb. Light a candle. Hold the foil with tweezers and blacken one side of the foil in the candle flame. Let the foil cool.



D. *Carefully* slide the foil back over the thermometer bulb. Use the tweezers to press the foil around the bulb. Try not to remove the black soot. Set the thermometer and foil, with the blackened side up, in direct sunlight as before. Observe the thermometer again for 5 minutes.



★ **16–4. In sunlight, how does the change in temperature of blackened foil compare with that of shiny foil?**

✔ 16–5. Why might a larger heat-absorbing surface capture more energy from the sun?

Dark surfaces absorb radiation and change it into heat energy. The energy captured can be used to raise the temperature of water. That's how a solar hot-water heater works. Sun's rays absorbed by a dark surface heat water. The hot water is stored in a tank until needed.

A large solar heater can heat water to over 90°C (194°F). That's plenty hot enough to heat a house, wash clothes, and take a bath. But it's not hot enough for cooking.

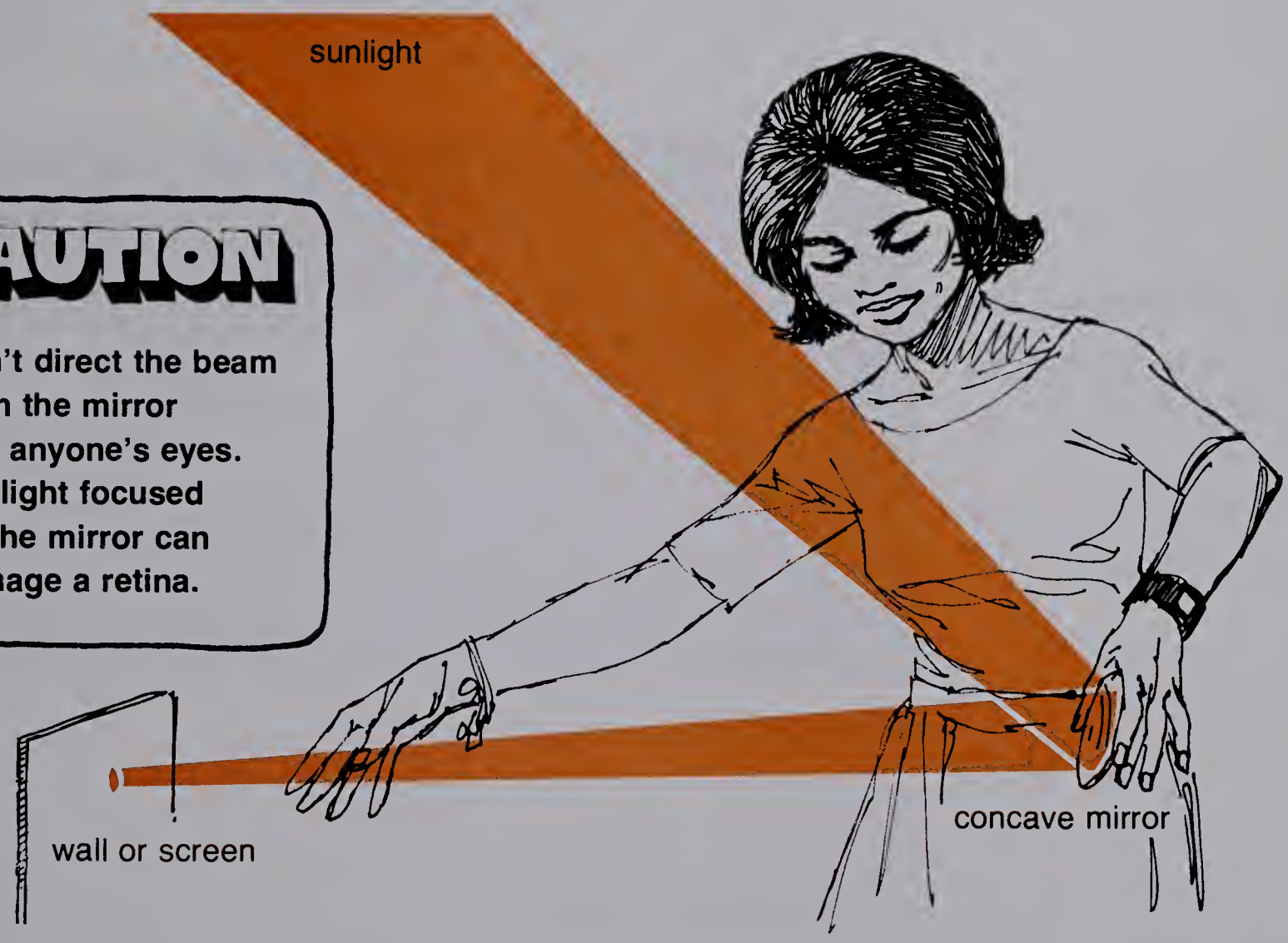
Very high temperatures can be gotten by concentrating the sun's rays. For an idea of how to do this, you will need a few minutes of sunlight and the following materials:

thermometer, 0–110°C
concave mirror

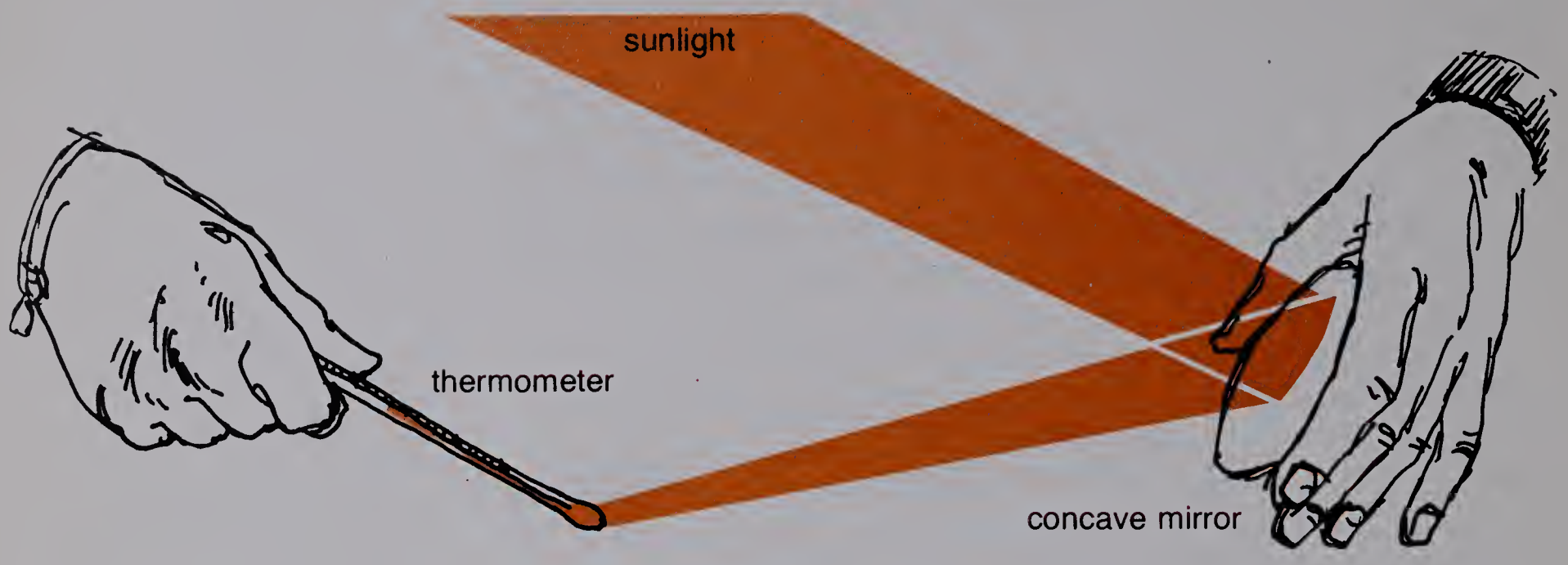
A. Using the mirror in sunlight, focus the sun's rays to the smallest possible spot on a desk top, wall, or screen. Write down the approximate distance from the mirror to the spot.

CAUTION

Don't direct the beam from the mirror into anyone's eyes. Sunlight focused by the mirror can damage a retina.



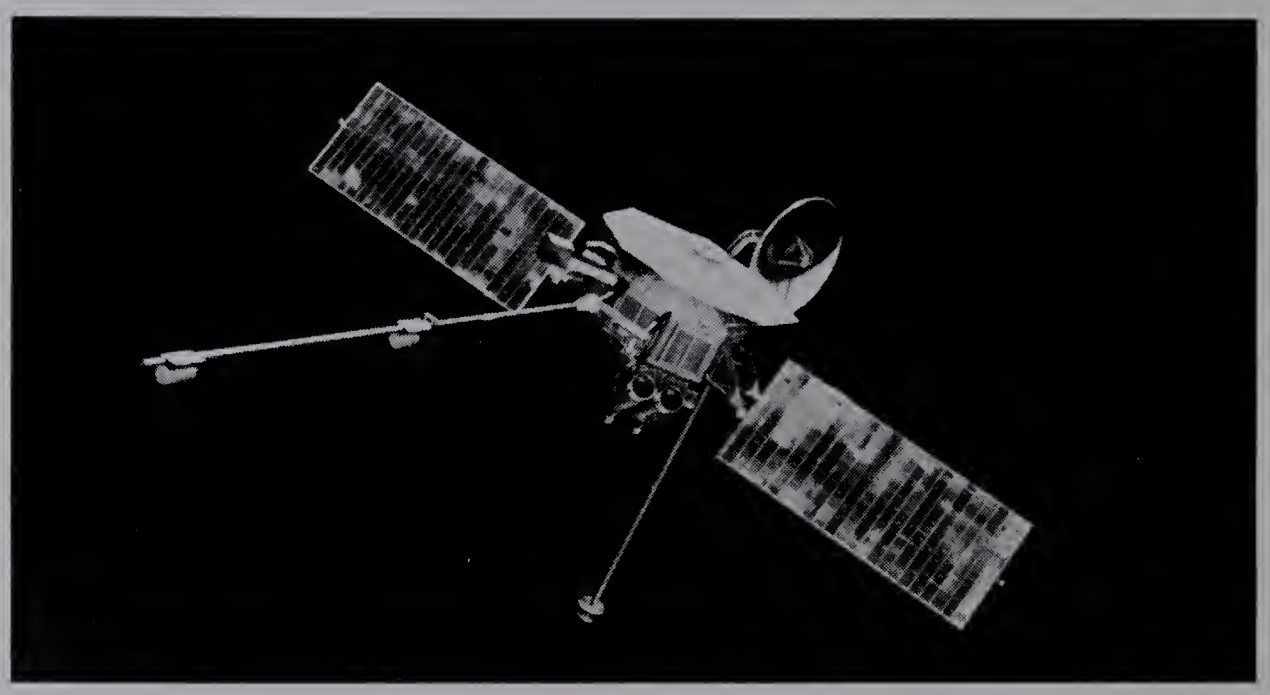
B. In sunlight, hold the thermometer in one hand and the concave mirror in the other. Focus the bright spot of light onto the thermometer bulb for a minute or so. Read the temperature.



✔ 16–6. What is the temperature change produced by the mirror?

Solar cookers with concave mirrors can boil water and roast meat. They develop temperatures as high as ovens in stoves. Some large solar furnaces will give temperatures high enough to boil iron!

Solar energy can also be captured by solar cells that convert sunlight to electricity. This is the way power is generated for satellites. The electricity can be used right away or stored in batteries.



Electricity for this satellite comes from the solar- cell panels.

✔ 16–7. How can solar cells provide energy for night use?

As the supply of coal, oil, and natural gas gets less and less, we will be looking more and more to solar energy. There's plenty of it, and it's free.

A Penny Saved Is a Penny Earned



When money is saved in household energy, it's usually done a penny at a time. Apart from heating or cooling your home, most energy is used by the hot-water system, refrigerator, and the cooking stove. So let's take a look at how you can save energy with these three appliances.

Hot-Water System

The storage tank in a hot-water system can be insulated so it doesn't lose heat rapidly. But the pipes leading from the tank are rarely as well insulated. So hot water in the pipes cools off. This wastes heat, as Figure 17–1 shows.

HOW HEAT IS WASTED

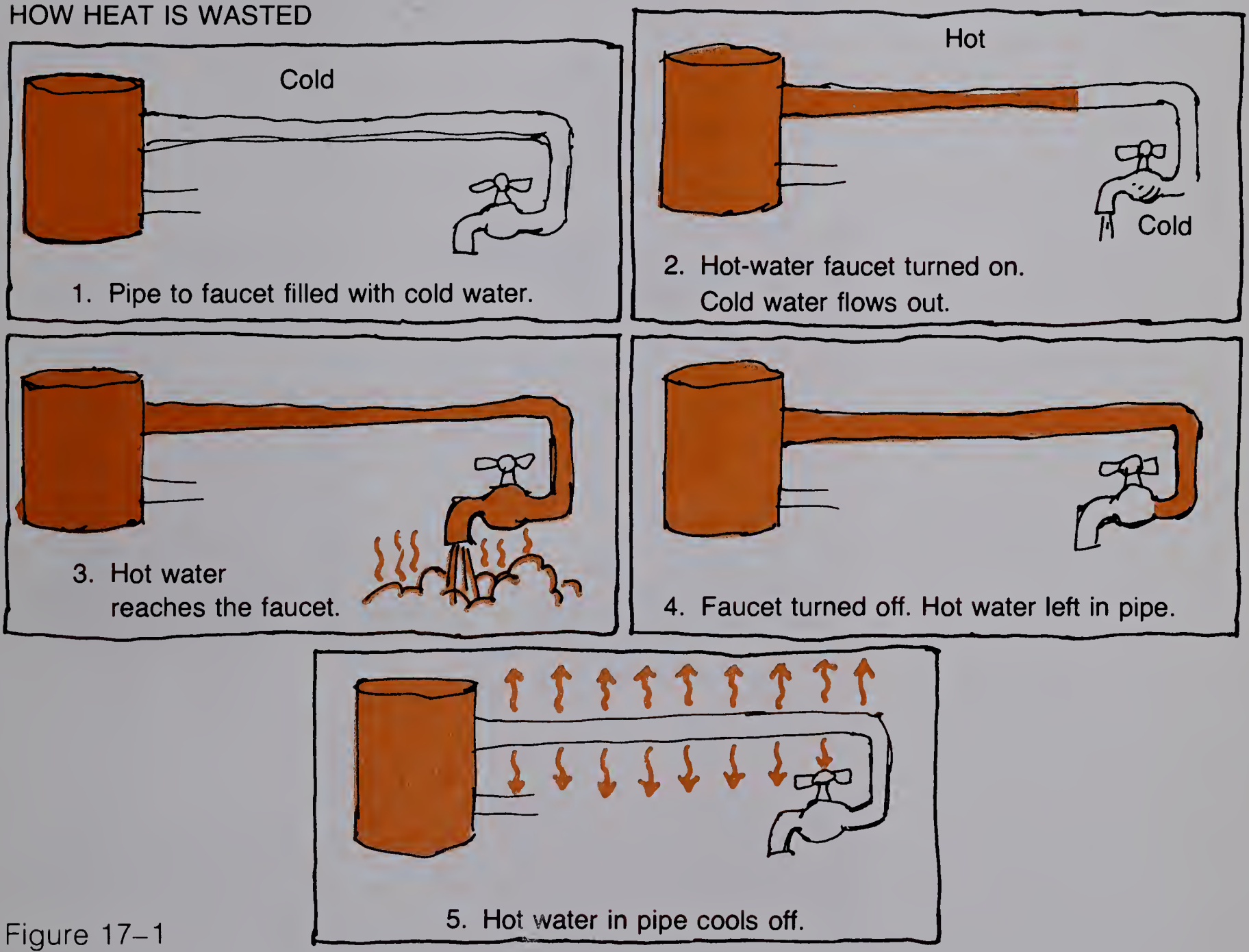


Figure 17–1

17–1. What happens to the heat from the hot pipes?

17–2. What effect might this have on an air-conditioning system in the summer?

HINTS ON SAVING ON HOT-WATER HEATING



1. Use cold water whenever you can.



2. Set bath times as close together as possible.



3. Set the thermostat as low as possible. A setting between 60°C and 66°C (140°F and 150°F) is usually high enough.



4. Repair leaky faucets as soon as possible.

17–3. How does Hint 2 save hot water?

✓ 17–4. How does Hint 3 save energy? (Refer to Activity 7 if you're not sure.)

★ **17–5. Water dripping from a leaky hot-water faucet may be quite cold. How then, does it save energy to stop it from dripping?**

Refrigerator

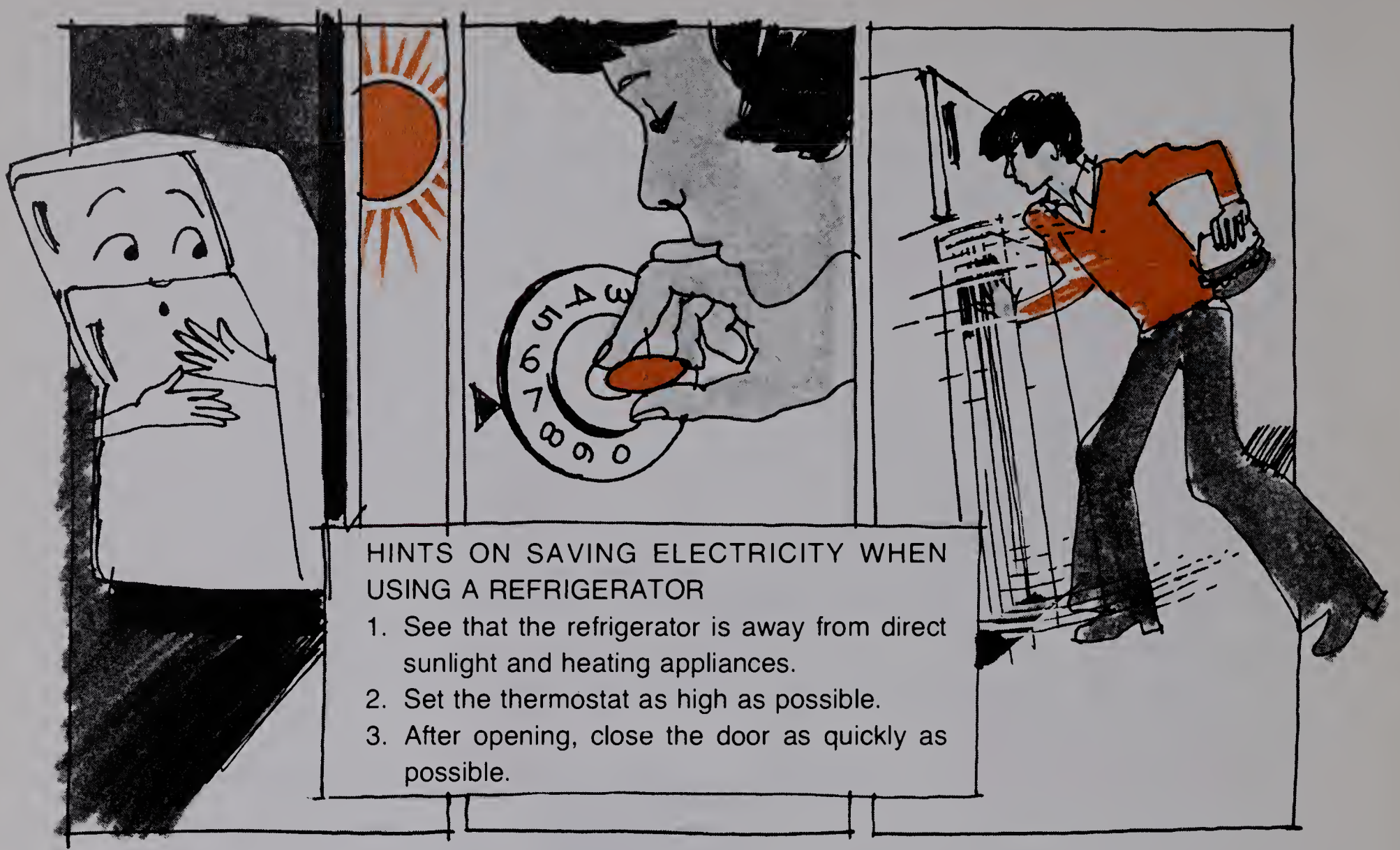
A frost-free refrigerator uses 39–50% more electricity than a regular refrigerator. So you pay for the convenience of not having to defrost your refrigerator.

A refrigerator is insulated to stop heat from getting in and cold air from flowing out. The rubber or plastic seal on the door is very important. If the seal isn't tight, the refrigerator motor will have to run longer.

You can check to see if the seal in your refrigerator should be replaced. Here's how to do it.



Close the refrigerator door on a piece of paper about the size of a dollar bill. Try to pull it out. Repeat the test at five or six different places around the seal. If you find any spot where the paper slides out easily, the seal should be replaced.



17–6. Why does Hint 2 for the refrigerator say the opposite of Hint 3 for the hot-water system?

Electric Stove

Most electric stoves have heating elements of different sizes. Usually, there is a 20-cm (8-inch) element that uses about 4000 watts and a 15-cm (6-inch) element that uses about 2500 watts.

Electricity is wasted when you use a bigger element than is needed. If you use the 20-cm element to heat a 15-cm pot, some of the heating element won't be under the pot. Here is a simple investigation you can try. You will need the following:

saucepan, 15 cm (6-inch) diameter
adhesive tape or grease pencil
clock or watch with second hand

A. Copy the table in Figure 17–2 in your notebook. Be sure the saucepan just covers the 15-cm (6-inch) element of the stove. Use the adhesive tape or grease pencil to mark the saucepan about ⅓ up on the inside. Fill the saucepan with cold water until the water is exactly level with the mark.



B. Turn the 15-cm element to its highest setting. In your table, write the number of seconds it takes for the water to come to a vigorous boil.



ELECTRICITY USED BY A STOVE

	WATTAGE	TIME (IN SECONDS)	WATT SECONDS
15-cm element	2500		
20-cm element	4000		



Figure 17–2



C. Empty the saucepan and cool it under water from the faucet. Then refill it with cold water to the same mark as in Step A. Place it on the 20-cm (8-inch) element. Turn the element to its highest setting. Time how long it takes for the water to boil vigorously. Record this time in your table.

17–7. Calculate the watt seconds of electricity by multiplying wattage by seconds. Fill in the third column of the table.

17–8. Which element used more electrical energy to bring the same amount of water to boiling?

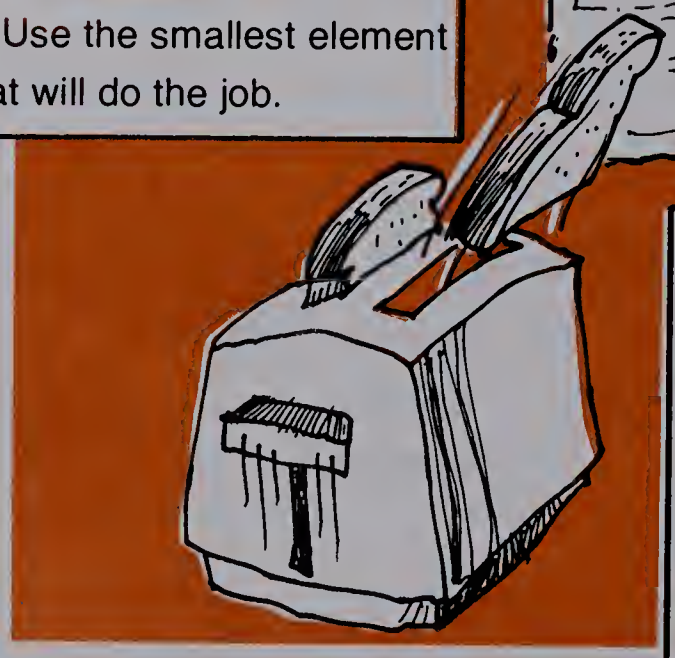
★ **17–9. Why does it take more electrical energy to bring the same amount of water to a boil on a burner that is larger than the pan than on a burner just as large as the pan?**

HINTS ON SAVING ELECTRICITY WHEN USING AN ELECTRIC STOVE

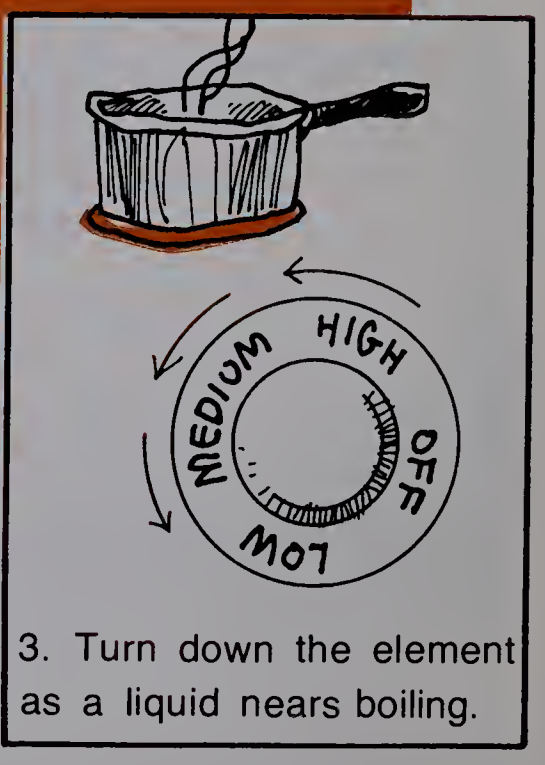


1. Use the smallest element that will do the job.





2. For small cooking jobs (making toast), use a smaller appliance (a toaster) rather than a larger one (the oven).



3. Turn down the element as a liquid nears boiling.

Retaining Energy



A dark or dull surface is a better energy absorber than a light or shiny one. For capturing energy, there's just one trouble with a dark surface. A good absorber is also a good radiator, so the dark surface gives energy away almost as fast as it gets it.

But there's a way of keeping the energy. It makes use of an interesting scientific principle called the *greenhouse effect.* It is illustrated in Figure 18–1.

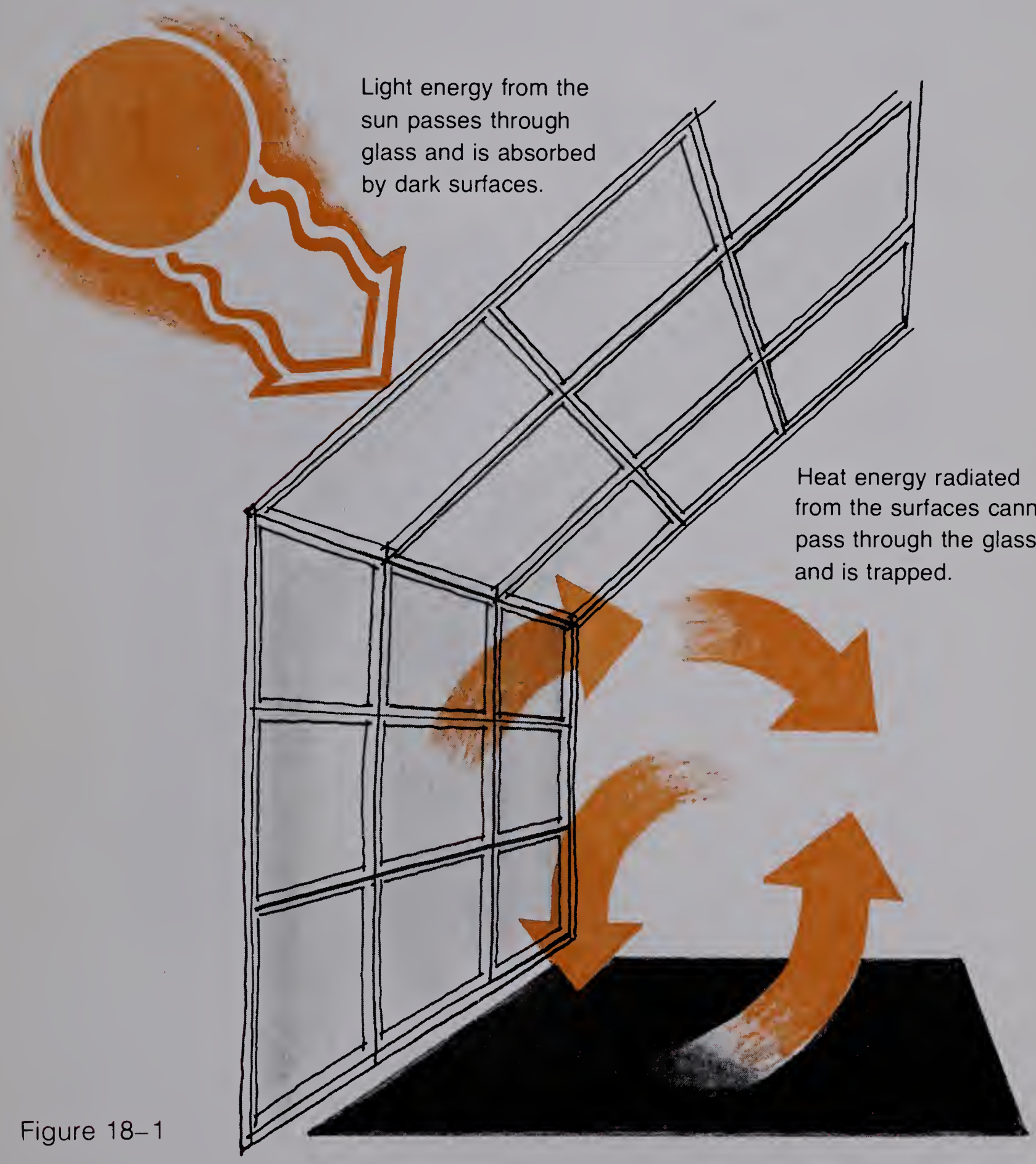


Figure 18–1

★ **18–1. Which passes more easily through glass, light or heat?**

You can show how glass or plastic can help keep heat energy. A plastic foam cup, a thermometer, a piece of plastic wrap, and some sunlight are all you need. Set up the investigation and then answer the following questions.

✔ 18–2. Briefly describe the procedure you used.

✔ 18–3. How well did the plastic keep heat energy from escaping?

★ **18–4. How do you think the fact that light goes through glass easier than heat does got to be called the greenhouse effect?**



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